BOOK OF ABSTRACTS

13TH EURO-MEDITERRANEAN SYMPOSIUM

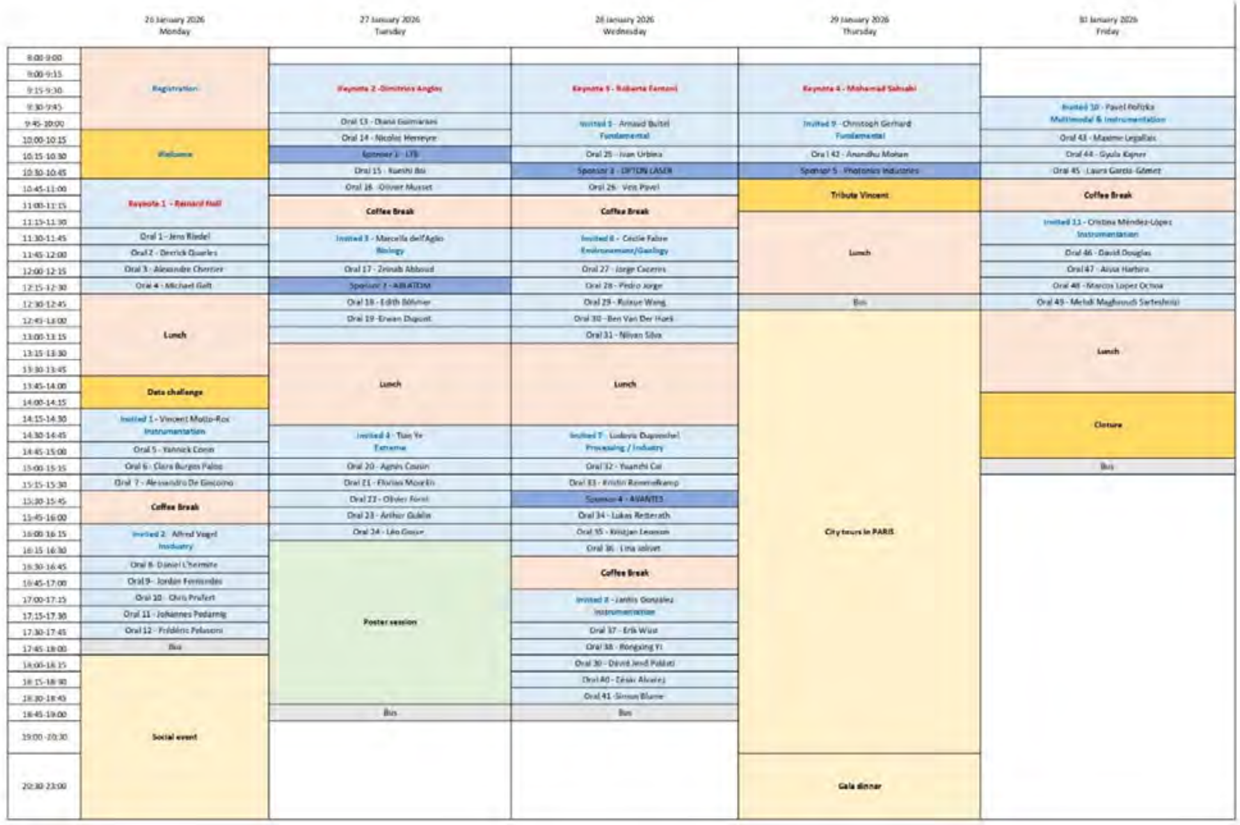
26th - 30th of January 2026

Senlis, France

LASER-INDUCED BREAKDOWN SPECTROSCOPY

TABLE OF CONTENTS

PROGRAM



	26 January 2026 Monday	27 January 2026 Tuesday	28 January 2026 Wednesday	29 January 2026 Thursday	30 January 2026 Friday
8:00-9:00	Registration				
9:00-9:15		Keynote 2 - Dimitrios Anglos	Keynote 3 - Roberta Fantoni	Keynote 4 - Mohamad Sabsabi	
9:15-9:30					
9:30-9:45					Invited 10 - Pavel Pořízka Multimodal & Instrumentation
9:45-10:00		Oral 13 - Diana Guimarães	Invited 5 - Arnaud Bultel Fundamental	Invited 9 - Christoph Gerhard Fundamental	
10:00-10:15	Welcome	Oral 14 - Nicolas Hermeyre			Oral 43 - Maxime Legallais
10:15-10:30		Sponsor 1 - LTB	Oral 25 - Ivan Urbina	Oral 42 - Anandhu Mohan	Oral 44 - Gyula Kajner
10:30-10:45		Oral 15 - Xueshi Bai	Sponsor 3 - OPTON LASER	Sponsor 5 - Photonics Industries	Oral 45 - Laura García-Gómez
10:45-11:00	Keynote 1 - Reinhard Noll	Oral 16 - Olivier Musset	Oral 26 - Vit Pavel	Tribute Vincent	Coffee Break
11:00-11:15		Coffee Break	Coffee Break		
11:15-11:30				Lunch	Invited 11 - Cristina Méndez-López Instrumentation
11:30-11:45	Oral 1 - Jens Riedel	Invited 3 - Marcella dell'Aglio Biology	Invited 6 - Cécile Fabre Environnement/Geology		
11:45-12:00	Oral 2 - Derrick Quarles				Oral 46 - David Douglas
12:00-12:15	Oral 3 - Alexandre Chevrier	Oral 17 - Zeinab Abboud	Oral 27 - Jorge Caceres		Oral 47 - Alisa Harbina
12:15-12:30	Oral 4 - Michael Gaft	Sponsor 2 - ABLATOM	Oral 28 - Pedro Jorge		Oral 48 - Marcos Lopez Ochoa
12:30-12:45	Lunch	Oral 18 - Edith Böhmer	Oral 29 - Ruixue Wang	Bus	Oral 49 - Mehdi Maghsoudi Sarteshnizi
12:45-13:00		Oral 19 - Erwan Dupont	Oral 30 - Ben Van Der Hoek	City tours in PARIS	Lunch
13:00-13:15			Oral 31 - Nilvan Silva		
13:15-13:30		Lunch	Lunch		
13:30-13:45					
13:45-14:00	Data challenge				
14:00-14:15					Cloture
14:15-14:30	Invited 1 - Vincent Motto-Ros Instrumentation				
14:30-14:45		Invited 4 - Tian Ye Extreme	Invited 7 - Ludovic Duponchel Processing / Industry		
14:45-15:00	Oral 5 - Yannick Conin				
15:00-15:15	Oral 6 - Clara Burgos Palop	Oral 20 - Agnès Cousin	Oral 32 - Yuanchi Cai		Bus
15:15-15:30	Oral 7 - Alessandro De Giacomo	Oral 21 - Florian Moselin	Oral 33 - Kristin Rammelkamp		
15:30-15:45	Coffee Break	Oral 22 - Olivier Forni	Sponsor 4 - AVANTES		
15:45-16:00		Oral 23 - Arthur Gublin	Oral 34 - Lukas Retterath		
16:00-16:15	Invited 2 - Alfred Vogel Industry	Oral 24 - Léo Gosse	Oral 35 - Kristjan Leosson		
16:15-16:30		Poster session	Oral 36 - Lina Jolivet		
16:30-16:45	Oral 8 - Daniel L'hermite		Coffee Break		
16:45-17:00	Oral 9 - Jordan Fernandes				
17:00-17:15	Oral 10 - Chris Prufert		Invited 8 - Jhanis Gonzalez Instrumentation		
17:15-17:30	Oral 11 - Johannes Pedarnig				
17:30-17:45	Oral 12 - Frédéric Pelascini		Oral 37 - Erik Wüst		
17:45-18:00	Bus		Oral 38 - Rongxing Yi		
18:00-18:15	Social event		Oral 39 - Dávid Jenő Palásti		
18:15-18:30			Oral 40 - César Alvarez		
18:30-18:45			Oral 41 - Simon Blume		
18:45-19:00		Bus	Bus		
19:00-20:30					
20:30-23:00				Gala dinner	

WELCOME

Dear Colleagues,

Welcome to the 13th EMSLIBS meeting!

We are delighted to welcome you to Paris to attend the 13th edition of the European Conference on Laser-Induced Breakdown Spectroscopy (EMSLIBS), taking place from the 26th to the 30th of January 2026.

Following the tradition of previous successful editions, we have designed a program that combines high-quality science with the opportunity to network in one of the world's most beautiful cities. This year's conference features a diverse scientific program with keynote presentations by leading experts, innovative contributions from both industry and fundamental science, and a special focus on multimodal applications and heritage science.

We would like to thank our sponsors for their support, which is essential to the success of this event. We hope you enjoy the scientific exchanges and the social events we have planned for you in the City of Light.

Sincerely,

Conference Chair

On behalf of the Organising Committee

FULL PROGRAM

DAY 1

MONDAY | 26TH JANUARY

08:00 | REGISTRATION

10:00 | Welcome

Fabien Lefebvre, Scientific Advisor, Research and Programs Department, CETIM

Isabelle Pallot-Frossad, President, Foundation for Heritage Science

Victor Etgens, head of the Research department, C2RMF (Cultural Ministry of France)

10:45 | SESSION 1: INDUSTRY 1 *CHAIRS: JEAN-BAPTISTE SIRVEN / CLARA BURGOS PALOP*

- **KEYNOTE 1: Reinard Noll** *Implementation of LIBS in industry – challenges, obstacles, and success stories*
- **11:30 | Oral 1 - Jens Riedel** *Introducing a Unified Formal Ontology for LIBS*
- **11:45 | Oral 2 - Derrick Quarles** *High-Speed Elemental Imaging via Kilohertz LIBS Imaging*
- **12:00 | Oral 3 - Alexandre Cherrier** *LIBS signal enhancement of analytes in liquids using microstructured substrates*
- **12:15 | Oral 4 - Michael Gaft** *LIBS and LIBS-MLIF for Isotopic Analysis of Mg, Ge, and Sn*

12:30 | *LUNCH*

13:45 | **Ludovic Duponchel : Data Challenge**

14:15 | SESSION 2: INSTRUMENTATION 1 *CHAIRS: OLIVIER MUSSET / LAURA GARCÍA-GÓMEZ*

- **14:15 | INVITED 1: Vincent Motto-Ros** *Element-specific challenges as a driving force for µ-LIBS imaging*
- **14:45 | Oral 5 - Yannick Conin** *Real-time Predictive LIBS Target Selection for Heterogeneous Materials via HSI-3D Sensor Fusion*
- **15:00 | Oral 6 - Clara Burgos Palop** *Laser Ablation Microsampling Enables Chemical Characterization of Meteorites by Single-Particle LIBS*
- **15:15 | Oral 7 - Alessandro De Giacomo** *Laser-Induced Breakdown Spectroscopy for In-Flight Elemental Analysis of Volcan Ash*

15:30 | COFFEE BREAK

16:00 | SESSION 3: INDUSTRY 2 *CHAIRS: PEDRO JORGE / LUISA LEMERLE*

- **16:00 | INVITED 2: Alfred Vogel** *Interplay between luminescence and thermomechanical events relevant for LIBS in air and water*
- **16:30 | Oral 8 - Daniel L'hermite** *LIBS development for stratigraphic oxygen analysis on metals*
- **16:45 | Oral 9 - Jordan Fernandes** *Revealing Microstructural Secrets of Alloys with High-Resolution LIBS Imaging*
- **17:00 | Oral 10 - Chris Prüfert** *LIBS in Ore Flotation, a Multi-Phase Case Study*
- **17:15 | Oral 11 - Johannes Pedarnig** *Surface cleaning monitored by LIBS and Optical emission spectroscopy*
- **17:30 | Oral 12 - Frédéric Pelascini** *LIBS activities at CETIM: from the laboratory to industry*

18:00 | VISIT / SOCIAL EVENT

K1

Implementation of LIBS in industy – challenges, obstacles, and success stories

R. Noll[*], J. Makowe, V. Moerkens, and M. Dargel

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The appeal of LIBS lies in the apparent simplicity of the process and its experimental implementation: a pulsed laser source, optics, spectrometer—and you're ready to go. This is undoubtedly why LIBS has been and continues to be embraced by numerous research institutions and universities far beyond the physics and chemistry departments. Since virtually all chemical elements can be analyzed in all states of aggregation, a wide range of applications is opening up. The machine learning methods that have emerged increasingly over the last decade and their easy accessibility have further driven this development.

In contrast, industrial implementations are still rather rare. The challenges involved and the obstacles to be overcome will be highlighted using examples. A selection of successfully implemented industrial applications of LIBS will demonstrate its potential for inline measurement directly in a processing line. An outlook will sketch challenging research and development topics for the future.

O1

Introducing a Unified Formal Ontology for LIBS

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In applied analytical Chemistry, laser induced breakdown spectroscopy (LIBS) has still not taken its deserved role as a standard routine for determining the elemental composition. As compared to alternative methods such as *e.g.* x-ray fluorescence (XRF), the applicability of LIBS is not reflected in the commonness of its implementation to solve real-life analytical tasks. Despite for LIBS, for XRD a wide range of experimental spectral libraries can be found, facilitating the use as a standard analytical tool. Oftentimes the strongly pronounced matrix effect, *i.e.* the characteristic answer pattern of a LIBS emission spectra depending on the samples' main components is named to be the main culprit for this underrepresentation. In strong contrast, another factor, its experimental simplicity, is commonly addressed as one of the main advantages of LIBS. In this talk, this flexibility is identified as an even stronger opponent to LIBS' widespread distribution, since a vast flexibility intrinsically hampers unified commonalities and eventually makes a comparison impossible. As a consequence of a lack of a harmonized agreement of common practice in LIBS, most databases are consisting of simulated spectra, not taking into account the individual impacts of minute experimental details. Since today, data analysis is the fastest growing field in all analytical sciences, LIBS, thus, misses out on a great opportunity to piggyback this nimbus. An obvious path to overcome this, is the use of semantic web technology, namely, formal ontologies as a means of digital knowledge representations.[1]

In this talk, a unified formal – i.e. machine interpretable – Ontology is presented, which is capable of summarizing and contextualizing all relevant metadata of any give experiment. If annotated, this metadata convention can make each LIBS spectrum universally understandable and eventually paves the foundation to the creation of libraries, not only containing data but a library of spectra representing a repository of generalized LIBS-information, interpretable in todays' semantic web formalism.

Despite the launch of the first academia-driven open-source Ontology for LIBS, this talk will give a number of practical examples why metadata, the additional content which allows for a translation of raw data into information, can be critical in LIBS as well. These case studies will cover the retrieval of additional information by designed modulation of the repetition rate, the influence of the excitation wavelength and pulse duration on the obtained LIBS spectra and the translation efforts from real-case space exploration spectra to calibration experiments conducted under earth´s atmosphere.

Keywords: Metadata, Harmonization, Digitalization, Semantic Web, Ontologies

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O2

High-Speed Elemental Imaging via Kilohertz LIBS Imaging

C. Derrick Quarles Jr. [1], Hunter B. Andrews[2], Benjamin T. Manard[2], Alex Zirakparvar[2], Joe Petrus[3], and Lyndsey Hendriks[4]

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[4] *University of Vienna, Vienna, Austria*

Laser-induced breakdown spectroscopy (LIBS) has become a very popular technique for spatially determining trace and major elements. LIBS offers the ability to measure C, H, O, N, and F, which are often difficult or unattainable by laser ablation–inductively coupled plasma mass spectrometry (LA-ICP-MS). In some examples, samples may exist with a somewhat (>25 cm2) large two-dimensional foot print while requiring spatially resolved elemental analysis. In such instances, larger samples may not be readily suitable for standard laser ablation chambers, therefore requiring a different sampling interface. Although LA-ICP-MS can perform high-speed imaging at 1,000 Hz, it requires small spot sizes and fast single pulse responses (<10 ms). For larger samples, greater spot sizes are required to keep the analysis within a reasonable time frame. In this case, LIBS is the ideal choice because the laser itself is the time limiting factor for measurements.

In this work, a new, large-format, high-speed LIBS system for analyzing samples that can be as large as 500 cm2 will be presented. This system uses a multichannel complementary metal–oxide–semiconductor (CMOS) spectrometer to collect the spectral signal from 190 to 1,100 nm. The laser used in this work was a 193 nm ArF excimer laser operated at 1,000 Hz and with a 50 x 50 µm to 200 x 200 µm laser spot size. The samples analyzed in this work included granitic pegmatite, granite, tree rings, and cave bear teeth. These samples varied in size, from 20 cm2 up to 400 cm2, resulting in an output of up to 2.5 million pixels per hour.

O3

Femtosecond laser microstructured substrate design for LIBS analysis of liquids

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Quantitative LIBS analyses have been successfully used in various fields, involving different sample types such as rocks, metals, glasses etc. Limits of detection (LOD) are strongly linked to the overall plasma emission, itself influenced by the laser ablation. Thus, detecting minor elements in liquid solutions or powders requires sample preparation in order to enhance the related LIBS signals. Powders are commonly prepared as pressed pellets and liquids are often deposited as droplet and dried onto a solid substrate prior to LIBS analysis. Moreover, nanoparticle enhanced LIBS (NELIBS) [1], which consists in depositing nanoparticles onto the sample surface, has been proven to provide significant LIBS signal enhancement, hence lowering the LOD. Our study aims at demonstrating that metallic samples that have been processed by femtosecond laser interaction can also induce LIBS enhancement.

Microstructuring of sample surface for the purpose of LIBS signal enhancement had been previously reported after subtractive manufacturing, with the use of a femtosecond laser [2]. In the present work, we investigate the effect of femtosecond subtractive microstructuring on the LIBS signal enhancement. The best enhancement for the Cu I line at 521.8 nm from the bare substrate was found to be 11. LIBS signal enhancement was found to be correlated to an increase in both electron density and temperature, with a 70% and 17% increase respectively, in the case of a 11-fold enhancement considered as our best substrate. Finally, the signal from the Ca I line at 527.0 nm of a dried droplet of mineral water deposited onto this substrate was compared to that obtained on a pristine, i.e. non-microstructured substrate (Fig.1). A 4-fold enhancement was observed [3].

Keywords: Femtosecond Laser microstructuring, LIBS, Signal enhancement, Droplet analysis

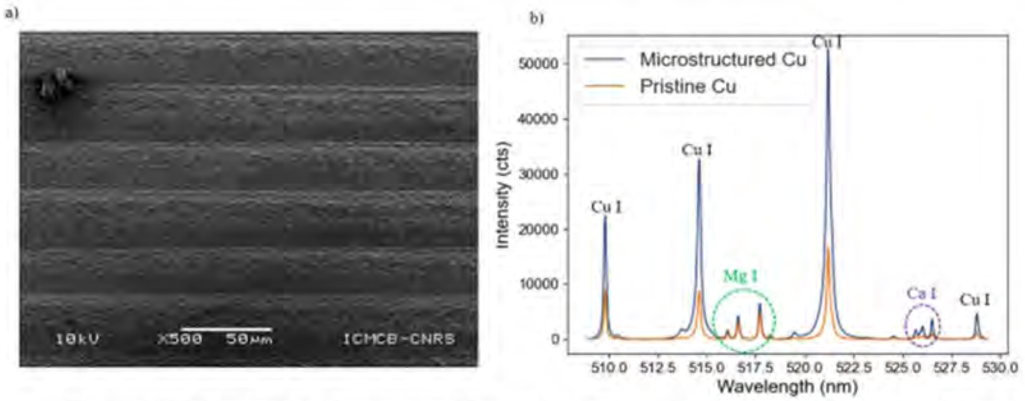

Fig 1. a) SEM image of a femtosecond laser microstructured copper b) LIBS spectra of the mineral water deposited and dried on top of our best microstructured copper substrate.

References

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[2] Q. Wang *et al.*, "Metal micro/nanostructure enhanced laser-induced breakdown spectroscopy", *Anal. Chim. Acta*, 2023, doi: 10.1016/j.aca.2023.340802.
[3] A. Cherrier, L. Canioni, and B. Bousquet, "LIBS signal enhancement by laser surface microstructuring of copper," Spectrochim. Acta B, 2025, doi: 10.1016/j.sab.2025.107318.

O4

LIBS and LIBS–MLIF for Isotopic Analysis of Mg, Ge, and Sn

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Isotopes are widely applied in scientific research and industry. Traditional methods for detecting isotopes include mass spectrometry, radiation detection from spontaneous radioactive decay, and neutron activation analysis. However, they all have drawbacks in practical applications, especially considering the potential for stand-off capability. LIBS is a promising way for real-time online analysis of isotopes. The vibrational and rotational components of molecular quantum energy levels strongly depend on the mass difference between isotopes. LAMIS is a well-known technique for isotopes analysis, mainly for light elements [1]. We demonstrated the feasibility of LAMIS for heavy REE and that its potential can be expanded by combining it with MLIF [2]. The topic of our presentation is the extension of this research for several metallic elements with atomic masses ranging from 24.3 to 118.7 amu. Magnesium, the lightest studied element, exhibits a strong MgO emission in LAMIS; however, the intensive lines belong to electronic transitions with $\Delta v=0$, which are not suitable for isotopic shift analysis (Fig. 1a). The (1-0) transitions have a significant theoretical isotopic shift of 0.6-0.5 nm, but it is extremely weak. Potentially, it may be overcome by LIBS-MLIF. Tin, the heaviest element, exhibits LAMIS with broad molecular bands and interfering atomic lines (Fig. 1b). The LIBS-MLIF enables the acquisition of several molecular transitions suitable for isotopic analysis in clear form (Fig. c). Germanium, intermediate in weight, exhibits LAMIS with weak and broad molecular bands and interfering Ge I atomic lines (Fig. 1d). The LIBS-MLIF enables the acquisition of several electronic transitions with large Δv, where the 0-5 one appears to be the most suitable for vibrational isotopic shift analysis (Fig. 1e), with an isotopic shift for ^{174}Ge and ^{170}Ge of 0.27 nm (28.9 cm^{-1}) (Fig. 1f).

Keywords: LIBS, MLIF, isotopes, Mg, Ge, Sn

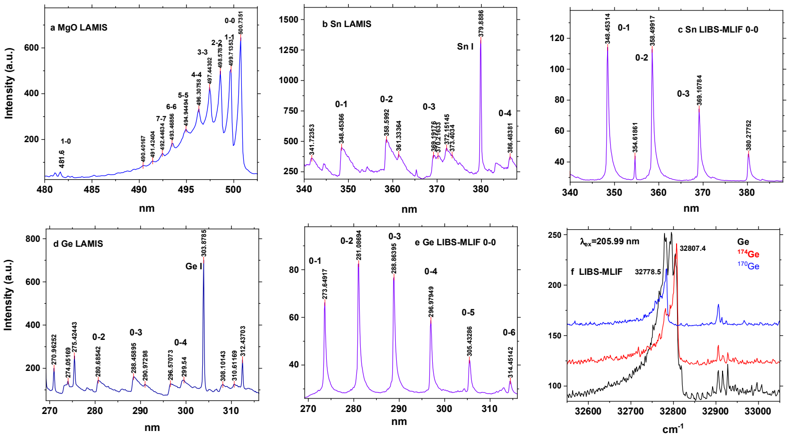

Fig. 1 LAMIS and LIBS-MLIF of Mg (a), Sn (b-c), and Ge with its isotopes

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I1

Element-specific challenges as a driving force for µ-LIBS imaging

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Laser-induced breakdown spectroscopy (LIBS) imaging has become a powerful approach for spatially resolved elemental analysis across a wide range of applications, from biology and medicine to industry and geosciences [1,2]. Its intrinsic multi-element capability, sensitivity to light elements, operation under ambient conditions, and micrometer-scale spatial resolution make LIBS a uniquely versatile all-optical imaging technique. Beyond its apparent universality, however, the practical implementation of LIBS imaging has often been driven by the analytical challenges associated with specific elements rather than by generic performance metrics alone. In this contribution, we revisit the development of µ-LIBS imaging through the lens of a few emblematic elements that have played a decisive role in shaping instrumental choices, detection strategies, and data-processing methodologies.

In particular, we first highlight gadolinium, which historically triggered many developments in LIBS imaging for the detection of nanoparticles in biological tissues (cf Fig. 1a), forcing the technique toward higher sensitivity, improved spatial resolution, and robust statistical treatment of sparse signals. We then address sulfur (cf Fig. 1b), a notoriously difficult element for LIBS imaging due to its emission lines located either in the deep UV—strongly affected by atmospheric absorption—or in the near-infrared, where detector sensitivity is limited. Finally, we discuss germanium, a critical metal of growing strategic importance, whose detection is constrained by a limited number of usable lines and severe spectral interferences with major elements such as Al, Ca, Pb, and Fe (cf Fig. 1c). Through these examples, this presentation emphasizes that while LIBS imaging is often presented as a broadly multi-elemental technique, achieving reliable and quantitative images for certain elements requires substantial experimental effort, careful optical and spectral optimization, and long-term methodological reflection.

Keywords: µ-LIBS imaging, Element-specific challenges, Trace element detection

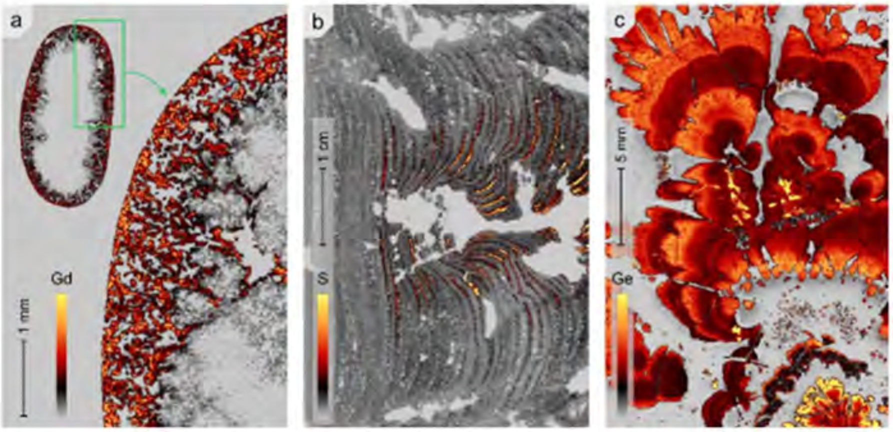

Figure 1. (a) Gadolinium imaging in a mouse kidney. (b) Sulfur imaging in a speleothem. (c) Germanium zoning in sphalerite.

References

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2 V. Gardette, V. Motto-Ros, C. Alvarez-Llamas, L. Sancey, L. Duponchel and B. Busser, *Anal. Chem.*, 2023, **95**, 49–69.

O5

Real-time Predictive LIBS Target Selection for Heterogeneous Materials via HSI-3D Sensor Fusion

Yannick Conin[1,*], Cord Fricke-Begemann[1], Sebastian Ulrich[1]

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Random or statistically distributed LIBS measurements can prove inadequate for heterogeneous materials where representative volumes exceed individual LIBS spot sizes (see Figure 1) and surface conditions vary dramatically. We present a sensor fusion approach that intelligently predetermines optimal LIBS measurement locations for real-time industrial sorting applications on moving conveyor belt systems.

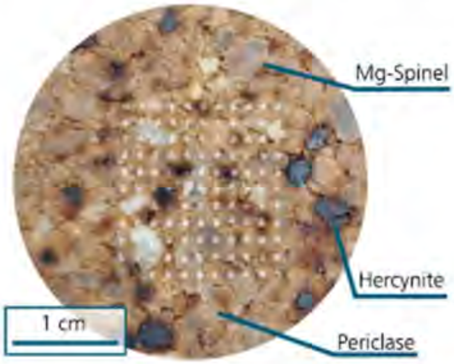

Fig. 1 Microscopic photo of a refractory test cylinder after a laboratory LIBS measurement with LIBS spots arranged in a grid of 11×11 spots.

Our architecture combines 3D surface topography data (capture via light section method) with hyperspectral imaging (HSI) to create comprehensive object characterisation before LIBS analysis. The 3D data enables object segmentation and surface quality mapping based on roughness and surface normal angles relative to the LIBS optical axis. Meanwhile, HSI data undergoes pixel-wise classification, generating material probability maps. A supervised convolutional neural network processes these data streams to forecast expected LIBS classification results at every pixel location.
To select regions of interest (ROI) for LIBS measurements on an object, the system analyses each possible ROI by calculating the expected information gain of a LIBS measurement at that location. That way, a set of ROIs is iteratively selected and transmitted to the active 3D beam guiding before the object reaches the LIBS measurement zone.
Demonstrated in the ReSoURCE project using three refractory materials, this predictive approach achieves >90 % classification precision from a single LIBS measurement, significantly outperforming classification from a randomly positioned LIBS measurement or HSI data alone.

Keywords: Real-time prediction; sensor fusion; heterogeneous materials, sorting, classification

ACKNOWLEDGEMENT

The ReSoURCE project is funded by the European Union's Horizon Europe Framework Programme (HORIZON) under the Grant Agreement Number 101058310.

O6

Laser Ablation Microsampling Enables Chemical Characterization of Meteorites by Single-Particle LIBS

C. Burgos-Palop[1,2], F.J. Fortes[1,2], P. Purohit[3], T. Delgado[1,2], J.M. Vadillo[1,2], J. Laserna[1]

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The chemical characterization of micrometeorites and heterogeneous meteoritic domains remains a significant analytical challenge due to their small size and limited availability. Here, a minimally invasive approach combining laser ablation, optical trapping, and single-particle laser-induced breakdown spectroscopy (µLA-OT-SP-LIBS) is presented for in situ analysis of discrete particles with minimal sample consumption. Bulk meteorite samples, including iron-rich (Campo del Cielo) and silicate-rich (Jbilet Winselwan, NWA 869, NWA 13739, Vaca Muerta) meteorites, were ablated to generate dry aerosols of spherical, multielemental particles, representative of the original sample composition. Individual particles were optically trapped in air and analyzed by LIBS. Complementary SEM, XRD, and XRF analyses confirmed particle morphology, elemental composition, and bulk mineralogy. The differences between the LIBS spectra were appreciable and a classification of the analyzed meteorites based on elemental composition was performed. For quantitative analysis, the major oxides were calculated using CF-LIBS.
In the carbonaceous chondrite Jbilet Winselwan, single-particle LIBS enabled the discrimination of particles originating from Fe-rich matrix and chondrules based on characteristic intensity ratios (e.g. Mg/Fe, Na/Fe), consistent with complementary analyses. Notably, CN molecular bands were detected in some matrix-derived particles, indicating the presence of native organic carbon. These findings demonstrate that µLA-OT-SP-LIBS can successfully characterize exiguous, discrete domains with negligible sample damage and absolute mass requirements in the low microgram range. The method provides a powerful platform for multielemental and molecular analysis of rare or valuable samples, with potential applications in meteoritics, geochemistry, and astrobiology

Keywords: laser ablation; meteorites; single-particle LIBS; optical trapping

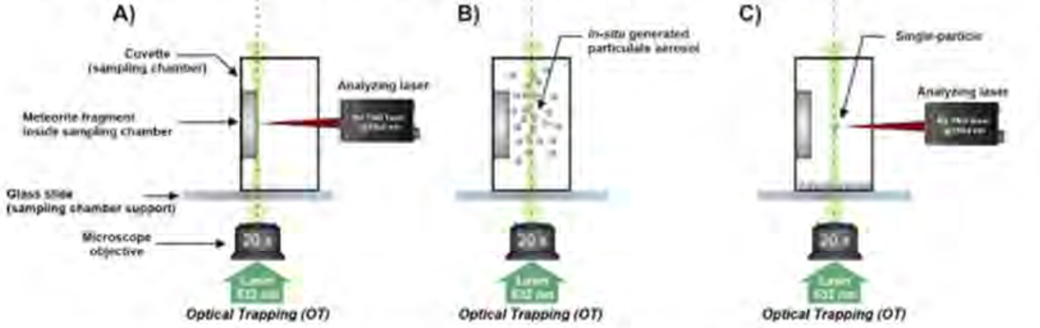

Fig. 1 Experimental procedure for particle generation, optical trapping, and in situ LIBS analysis.

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O7

Laser-Induced Breakdown Spectroscopy for In-Flight Elemental Analysis of Volcan Ash

Alessandro De Giacomo[1,2], Aya Taleb[1], Marcella Dell'Aglio[2], Rosalba Gaudiuso[1], Daniela Mele[3], Pierfrancesco Dellino[3]

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Real-time analysis of fine ash in volcanic plumes, which represents magma fragments expelled from the crater during explosive eruptions, is a valuable tool for volcano monitoring and hazard assessment. In this paper, in-flight LIBS experiments based on self-calibrated approaches are used to determine the elemental composition of suspended volcanic ash [1].

To this aim, an ultralight, compact LIBS system has been designed to be mounted on an eightpropeller drone. In order to simplify the technology and bypass issues related to the lack of reproducibility during in-flight measurements, the quantitative analysis is performed using a fully selfcalibrated analytical method, including calibration-free LIBS. This approach is based on the calculation of the spectral radiance of a uniform plasma in apparent local thermodynamic equilibrium. In short, for each measurement, the system self-calibrates the spectral response by forcing all emission lines of each element to follow an apparent Boltzmann distribution. The calibration-free approach is then applied for quantitative analysis.

Although from a theoretical point of view the proposed method strictly works only if it is assumed that any deviation from equilibrium is the same for all elements during the integrated time measurement, previous laboratory tests have shown excellent quantification down to 0.1% [2], while trace elements are detectable but not quantifiable.

Finally, instrumental aspects related to LIBS sensor-drone coupling and real in-flight ash measurements will be critically discussed to highlight perspective and limits. **Keywords:** LIBS sensor; Drone; Self Calibration;

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I2

Interplay between luminescence and thermomechanical events relevant for LIBS in air and water

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Creation of sufficient ablated material for LIBS requires high-density plasma as a starting point but material analysis relies on the detection of line spectra at the luminescent low-density plasma/ excited vapor stage reached after plasma expansion and cooling. Understanding the evolution of temperature and pressure distributions and its interplay with luminescence signatures is pivotal for signal interpretation and optimization. Plume dynamics after water ablation in air and the cavitation bubble dynamics after optical breakdown in bulk water are taken as examples for an analysis of this interplay.

Interplay in air. Water is ablated by 2940-nm, 60-ns Er:YAG laser pulses, and the plume dynamics analyzed by stroboscopic white-light schlieren color photography [1]. Initial plume and ablative recoil pressure are deduced from shock wave propagation speeds via Hugoniot relations for air and water. Plume color contains info on local vapor and mixed-phase states and on droplet size. The compression of ambient air during plume expansion results in a back-propagating inner shock wave that reheats and mixes central plume regions. Such vivid evolution of the global pressure and temperature distribution will occur also after plasma-mediated ablation and influence light emission in LIBS.

Interplay in water. For ambient pressures p_∞ between 0.1 MPa and 50 MPa, the breakdown dynamics produced by 1064-nm, 8-ns Nd:YAG laser pulses is investigated by simultaneous ICCD detection of plasma luminescence and shadowgraph imaging, combined with PMT recordings of integrated luminescence intensity. Bright luminescence at large p_∞ during the entire bubble oscillation indicates the feasibility of deep-sea LIBS. Numerical simulations fitted to measured bubble oscillation and shock wave emission data [2] provide the bubble pressure evolution $P(t)$ from breakdown through collapse. Spectroscopic analysis of initial blackbody-like plasma emission and line spectra for $t \geq 70$ ns yields the temperature evolution $T(t)$ [3]. Spatial and temporal evolution of plasma luminescence at different p_∞ are explained based on $P(t)$ and $T(t)$ deduced from thermomechanical events & plasma size. Early $T(t)$ data provide info on energy conversions during the plasma-vapor phase transition. Pressure within the bubble equilibrates already within ≈ 40 ns but electron density and temperature gradients from center towards wall persist during bubble expansion (at large p_∞ during its entire oscillation). We discuss implications for interpreting spectroscopic data and perspectives for future modeling efforts.

Keywords: Water ablation; laser-induced cavitation; plasma temperature, plasma pressure.

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O8

LIBS development for stratigraphic oxygen analysis on metals

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Oxygen measurement on metal surface is very important for durability of industrial facilities in order, for exemple, to study corrosion problem or to characterize innovative metallic coating. LIBS is a good technique to characterize big aera (compare to SEM) and to analyze layer by layer the amount of oxygen in depth but because we are living in air composed of around 20% O2 the measurement is not as easy as it seems.

We have developed an instrumentation with Ar gaz blowing and studied different protocols to have the best results. We will present the instrumentation and will compare measurements obtained on aluminum sample using a "bad" protocol and a "good" protocol (Fig. 1). The results will be discussed.

Then, with the well-adapted protocol, we characterized deposit on steel sample coming from an experimental loop simulating industrial tube and we will show the capability of LIBS to do such measurements.

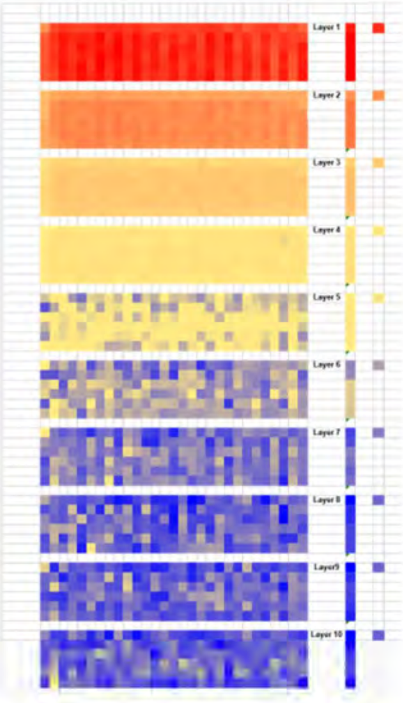

Fig. 1 Example of layer by layer oxygen intensities measured on an aluminum plate

Keywords: LIBS; mapping; stratigraphy; spectroscopy; analysis; laser

O9

Revealing Microstructural Secrets of Alloys with High-Resolution LIBS Imaging

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Micro-LIBS mapping is a powerful technique for investigating the local chemical composition of materials. Its ability to perform rapid, multi-elemental, and minimally destructive analyses makes it particularly suitable for studying microstructural heterogeneities in alloys, with high sensitivity to both high- and low-atomic-number elements [1, 2]. Recent improvements in lateral resolution now make LIBS comparable to conventional characterization techniques such as SEM-EDS. This progress enables the detection of thin defects and inclusions (metallic or non-metallic) at the microscopic scale (~µm), providing a valuable tool for quality control and material assessment.

In this presentation, we will describe an original LIBS system equipped with a high-numerical-aperture objective (×50 magnification) and a visible laser (532 nm) operating at 1 kHz with a Gaussian beam profile. The detection system is optimized for both UV and visible spectral ranges. To demonstrate the instrument's performance in terms of both resolution and sensitivity, several metallic alloy samples (aluminum, copper, and steel) were analyzed. Elemental distributions were recorded across the sample surfaces with a lateral resolution down to 1 µm, revealing pronounced heterogeneities in the spatial distribution of alloying elements, as illustrated in Figure 1. Despite the very limited ablated volume, excellent detection sensitivity was achieved. These results open promising perspectives for metallurgical applications, particularly for the study of light and transition elements at the microscale.

Keywords: Micro-LIBS; High spatial resolution; Metallic alloys; Microstructural heterogeneities.

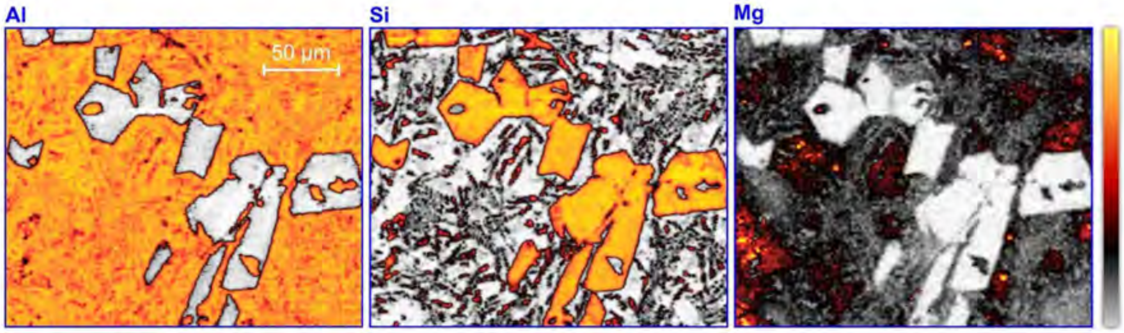

Figure 1: Element images obtained at 1 µm lateral resolution on a Aluminum reference allows (MBH-54× GS20J1 E).

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O10

LIBS in Ore Flotation, a Multi-Phase Case Study

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Keywords: Industry and Energy; Monitoring, Real-Time, Froth

We present a case study on the application of laser-induced breakdown spectroscopy (LIBS) as a monitoring tool for ore flotation, a multi-phase system. The current gold standard for elemental analysis in industrial processes relies on inductively coupled plasma (ICP) techniques, specifically ICP-OES and ICP-MS. While these methods provide highly accurate results, they require chemical digestion and purification of solid samples, making them time-consuming and unsuitable for real-time process control In contrast, LIBS, which also is an optical emission technique, offers a more practical, real-time, and in situ approach to monitoring flotation processes, an increasingly important capability in the context of Industry 4.0 developments. However, applying LIBS in a flotation environment presents significant challenges due to the highly dynamic surface topology and composition of the froth-slurry system Plasma ignition can occur on aerosols, froths, or within slurries, all of which create complex and potentially unstable measurement conditions.

To address these challenges, we employed a diode-pumped, Q-switched Nd:YAG laser (40 mJ, 20 Hz) as the light source, using an argon-flushed, enclosed, free-standing optical path with a 200 mm focal length. Strong argon purging within the MAYA2000Pro spectrometer, as proposed elsewhere [1], was implemented to reduce froth splashing onto the laser and collection optics and to enhance overall signal intensity.

The resulting single-shot spectra were classified using an autoencoder-based algorithm to determine whether each spectrum corresponded to a valid plasma event. Further levels of classification were applied based on the respective experimental conditions. Additionally, monitoring element-specific emission lines allowed us to observe trends throughout the flotation process and evaluate elemental ratios relevant to process performance.

Our next steps include developing a predictive model for both froth and slurry composition and refining the algorithm to provide real-time feedback for process optimization and control.

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O11

Surface cleaning monitored by Laser-induced breakdown spectroscopy and Optical emission spectroscopy

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The cleaning of surfaces with atmospheric pressure plasma jet (APPJ) is investigated by in-situ optical emission spectroscopy (OES) and ex-situ laser-induced breakdown spectroscopy (LIBS). Metallic and dielectric samples are coated with lubricant layers of 1.1 to 7.1 µm thickness and the sample surfaces are treated by APPJ plasma. Light collected at the sample surface during APPJ treatment is analyzed by OES. LIBS chemical imaging of treated surfaces delivers spatial cleaning profiles (Fig. 1).

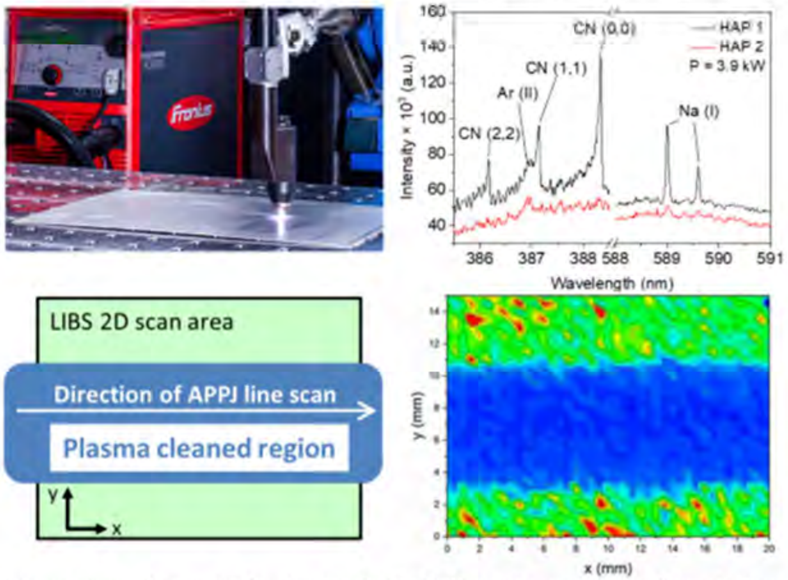

Fig. 1: Atmospheric pressure plasma jet device (top left). OES spectrum measured in-situ (top right). Geometry of APPJ line cleaning (bottom left). LIBS chemical image of plasma cleaned line (CN emission; bottom right).

From measured emission intensities of the CN molecular band and the Na atomic line the cleaning efficiency (CE) for carbon and for Na containing contaminants is determined. APPJ surface cleaning is efficient, CE is up to 95 %, as is confirmed by X-ray photoelectron spectroscopy, fluorescence measurements, and contact angle measurements. Thermal and non-thermal processes are contributing to plasma surface cleaning. For the carbon containing contaminant thermal processes are dominating (~90 %) while also non-thermal processes (~30–45 %) are relevant for the Na containing component. The cleaned surface area per time (0.3–10 cm²/s) can be upscaled. The results highlight the potential of plasma surface cleaning under ambient conditions.

Keywords: Laser-induced breakdown spectroscopy (LIBS); Optical emission spectroscopy (OES) Atmospheric pressure plasma jet (APPJ); Surface cleaning; Cleaning efficiency.

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O12

LIBS activities at CETIM: from the laboratory to industry

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The French technical center for mechanical industries (Cetim) is involved in numerous research projects. Among them, chemical elemental analysis is of paramount importance to the mechanical industries; one of the key development paths is the deployment of innovative technologies such as LIBS. As a technological accelerator, Cetim aims to bridge the gap between academic research and the industrial implementation of Laser-Induced Breakdown Spectroscopy. Our current research roadmap is driven by three complementary strategic axes designed to address robustness and versatility requirements in industrial environments: Calibration-Free quantification, high-speed imaging, and online process monitoring.

The first axis focuses on the development of reliable Calibration-Free (CF-LIBS) methods. The objective is to overcome instrumental limitations, such as the instability of high-resolution spectrometers, and to compensate for the lack of accurate spectroscopic data in current databases. By developing intrinsic calibration strategies, we aim to enable accurate quantification without relying on complex external standards that are often impossible to implement in industrial processing lines. In parallel, our second research axis explores elemental imaging, specifically targeting the detection of light elements (atomic number < 11) to address critical needs in the mechanical sector, such as carbon distribution and hydrogen embrittlement analysis.

Finally, we highlight the potential of online LIBS as a robust solution for real-time process control. This third axis is illustrated through three concrete "lab-to-industry" proofs of concept (POCs) deployed in severe environments. These examples demonstrate the versatility of the technique across different states of matter: hybrid data fusion for polymer extrusion monitoring, direct analysis of molten metal pouring streams for digital traceability, and real-time lithium concentration monitoring in geothermal extraction processes. Collectively, these advancements underscore the role of LIBS as a pivotal sensor technology for the industry of the future.

Keywords: Industrial LIBS; Calibration-Free; Elemental Imaging; Online Monitoring.

DAY 2

TUESDAY | 27TH JANUARY

09:00 | SESSION 4: CULTURAL HERITAGE *CHAIRS: CRISTINA MÉNDEZ-LÓPEZ / ARTHUR GUBLIN*

- **09:00 | KEYNOTE 2: Dimitrios Anglos** *LIBS on demand. Addressing niche and broader challenges in Heritage Science*
- **09:45 | Oral 13 - Diana Guimaraes** *Augmented Spectral Reality for Cultural Heritage Interpretation*
- **10:00 | Oral 14 - Nicolas Herreyre** *μ-LIBS imaging for archaeological ceramic characterization*
- **10:15 | Sponsor 1: LTB (Steffen Mittelmann)** *Overview of LIBS applications and projects governed by LTB*
- **10:30 | Oral 15 - Xueshi Bai** *LIBS technique for the conservation of aluminum aircrafts*
- **10:45 | Oral 16 - Olivier Musset** *Fusion of LIBS Imaging and C&O Isotopic Optical Spectroscopy in Carbonates*

11:00 | COFFEE BREAK

11:30 | SESSION 5: BIOLOGY, HEALTH AND AGRONOMY *CHAIRS: JORGE CACERES / ORSOLYA URBÁN*

- **11:30 | INVITED 3: Marcella dell'Aglio** *Laser-induced plasma and biosensing: coupling LIBS with Lateral Flow Immunoassay*
- **12:00 | Oral 17 - Zeinab Abboud** *Methodology for using portable LIBS in the field of occupational health*
- **12:15 | Sponsor 2: ABLATOM (Florian Trichard)** *From laboratory to industrial processes, advanced elemental analysis*
- **12:30 | Oral 18 - Edith Böhmer** *CF-LIBS: Screening of Human Lifestyle Using Fingernails*
- **12:45 | Oral 19 – Erwan Dupont** *Development of matrix-matched standards for LIBS Imaging*

13 :00 | LUNCH

14:30 | SESSION 9: PROCESSING AND CHEMOMETRICS *CHAIRS: BRUNO BOUSQUET/MEHDI MAGHSOUDI SARTESHNIZI*

- **14:30** | **INVITED 4: Tian Ye** *Underwater LIBS towards deep-sea applications*
- **15:00** | **Oral 20 - Agnès Cousin** *Overview of the Mars2020 mission and main results from SuperCam*
- **15:15** | **Oral 21 - Florian Mourlin** *LIBS in airless environments: from the lab to the Moon and beyond*
- **15:30** | **Oral 22 - Olivier Forni** *Elemental sulphur deposit and its related enrichments as viewed by Chemcam*
- **15:45** | **Oral 23 - Arthur Gublin** *Investigation of Uranium Emission Lines for Isotopic Analysis*
- **16:00** | **Oral 24 – Léo Gosse** *LIBS for fusion: tungsten and boron spectral characterization*

16:15 | POSTER SESSION

K2

LIBS on demand.
Addressing niche and broader challenges in Heritage Science

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The increasing demand for minimal intervention, in combination with restrictions in sampling and transportation of cultural heritage and archaeological objects, has generated strong interest in developing and utilizing analytical techniques and instrumentation capable of working outside the framework of large facilities or specialized research laboratories. In this context LIBS, a highly versatile technique, demonstrated for its capacity to work in the field, has been successfully configured in the form of specialized instrumentation suitable for addressing the needs of researchers in the field of Heritage Science.

In this presentation, we review our experience with developing custom LIBS instrumentation aiming to support the work of art conservators, historians and archaeologists and report on recent results. Depending on specific analytical requirements, dictated by particular applications different design aspects have been adopted ranging from compact, portable systems [1] to hybrid spectrometers [2] or a dedicated LIBS microscope [3]. Relevant design concepts are discussed with emphasis on ease of use and user interfacing. Examples of selected case studies are presented not only highlighting results but also focusing on current and future challenges.

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O13

Augmented Spectral Reality for Cultural Heritage Interpretation

Diana Guimarães[1], Rafael Cavaco[1], Luana Pereira[1,2], Diana Capela[1,2], Pedro Jorge[1,2] and Nuno A. Silva[1]

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Elemental analysis of cultural heritage materials provides crucial information for the restoration, preservation, and authentication of heritage artifacts. Such analyses reveal the composition of pigments, alloys, and other materials, offering insights into ancient manufacturing techniques and degradation processes.

However, their results are often limited to static two-dimensional maps detached from the object's physical form. This work presents an Augmented Reality (AR) framework[2] that integrates spectral imaging with 3D digitization to create interactive digital replicas of heritage objects, such as Portuguese tiles. The workflow builds upon a methodology that combines RGB and spectral data clustering to minimize the number of laser shots required in LIBS analyses, reducing the risk of damage while maintaining chemical representativeness. Extending this principle to AR environments enables users to visualize, manipulate, and explore the data in real time. Ultimately, the proposed framework bridges spectroscopy, 3D visualization, and human interaction, contributing to a new paradigm of Augmented Spectral Reality, allowing users to *see what the eyes can't* in the study of cultural heritage.

Keywords: Laser-induced Breakdown Spectroscopy, Clustering Algorithms, Minimal Damage, Augmented Reality

Fig. 1. Illustration of the final user-friendly interface in Unity.

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O14

μ-LIBS imaging for archaeological ceramic characterization: toward quantitative imaging applied in provenance studies

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In our pursuit of characterizing pottery and ancient ceramic productions, we are pioneering a novel approach using μ-LIBS (Laser-Induced Breakdown Spectroscopy) for multi-analytical characterization. This technique generates extensive spectral datasets—sometimes exceeding one million spectra—across a sample surface, enabling spatially resolved elemental analysis with micrometric precision. From these data, we produce maps dedicated to petrographic identification and estimation, including mineral family classification and grain size distribution, which are invaluable for understanding technical history, craftsmanship, and provenance of pottery [1].

Beyond petrographic mapping, the true innovation of μ-LIBS for ceramic studies lies in its capacity to isolate and quantify the clay fraction independently of the temper (sandy fraction). Unlike conventional bulk techniques such as XRF or ICP-AES, μ-LIBS provides spatially resolved compositional data, allowing for precise segmentation and exclusion of temper contributions. This enables a focused quantitative analysis of the clay matrix alone—a critical advancement for comparative studies of pottery samples, regardless of their temper composition [2]. By eliminating the variability introduced by temper, μ-LIBS enhances our ability to identify raw material sources and determine the provenance of vessels.

To achieve this, we developed a new approach so called Q-LIBS clay, which relies on calibration based on XRF measurements of the same ceramic to produce semi-quantitative images. Grain segmentation then allows for the determination of the clay fraction composition. This method has been validated on experimental ceramics and is now being applied to specific archaeological questions.

As a case study, we examined the calcareous production of Lugdunum (ancient Lyon, France), which includes both coarse productions with sandy clay (*amphorae*) and fine productions with clayey material only (*terra sigillata*). Our investigation of "La Muette" workshop demonstrated that a group of *amphorae* was produced using the same raw natural clay as a group of calcareous *sigillata*, providing geochemical evidence for shared raw material sources.

Keywords: μ-LIBS imaging; quantification; petrography; archaeological ceramic.

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S1

Overview of LIBS applications and projects governed by LTB

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This contribution presents selected recent projects of *Lasertechnik Berlin GmbH* in the field of laserinduced breakdown spectroscopy (LIBS) with a focus on industrial and high-speed applications. The main emphasis is placed on the development of a novel online, in-situ slag analysis system *MoMa Lance* designed for real-time monitoring of slag composition in electric arc furnaces (EAFs). The system enables the continuous elemental analysis and will be applied to investigate the influence of hydrogen addition during melting on the reduction behavior of iron and titanium in the slag.

In addition, we demonstrate the capabilities of a combined Raman–LIBS system for the detection and identification of micrometer-sized surface contaminations on optical components. Finally, first results from fast-LIBS measurements on aluminum, copper, and steel samples using a newly developed actively Q-switched DPSS laser are presented, highlighting the potential for high-resolution material mapping in a kHz-mode.

Keywords: slag analysis, in-situ LIBS, Raman-LIBS, fast mapping.

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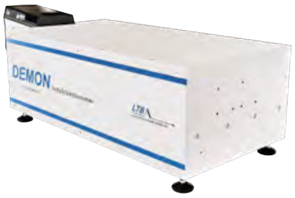

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O15

LIBS technique for the conservation of aluminum aircrafts

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The conservation of aluminum aircrafts of the Musée de l'Air et de l'Espace (MAE) in France presents significant challenges because the addition of alloying elements necessary to increase mechanical properties of aluminum drastically reduces its corrosion resistance. These large-scale objects often exhibit various surface treatment, and diverse corrosion morphologies that require precise analytical tools capable of guiding conservation treatments while remaining minimally invasive. In this context, Laser-Induced Breakdown Spectroscopy (LIBS) provides a highly suitable technique to characterize the aluminum alloys composition and for assessing their degradation state. In the context of the C-ADER[1] ANR Project a mission was conducted in the storage room of the MAE using a mobile LIBS system [1] to perform in situ diagnostics directly on the aircraft structures.

LIBS analyses performed on aircraft components demonstrate the technique's capability to reconstruct stratigraphic sequences through depth-resolved ablation. LIBS spectral signatures differentiate base metal, surface treatment, paint layers, and corrosion products. Emission profiles reveal characteristic alloying elements (Cu, Mg, Mn) as well as corrosion markers such as AlO and hydrogen. These results confirm LIBS as a mobile, multi-element, and minimally invasive tool can suit for diagnosing large metallic cultural-heritage objects. The technique provides rapid insight into alloy structure and corrosion processes, and it allows to plan conservation strategies such as inhibitor treatments currently under evaluation.

Keywords: LIBS; cultural heritage; aluminium alloys; corrosion; aircraft conservation

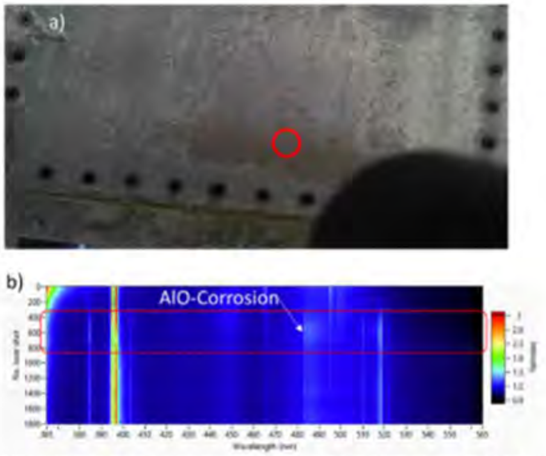

Fig. 1 a) Analysed point on the plane; b) Emission intensity as a function of the depth (number of laser shot)

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O16

Fusion of LIBS Imaging and C&O Isotopic Optical Spectroscopy in Carbonates

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Chemical analysis of carbonates provides important information for determining the conditions or environment in which rocks formed, thereby helping to better understand past climates. The most common analysis performed on carbonates involves measuring the isotopic ratios $\delta^{13}C$ and $\delta^{18}O$. LaserInduced Breakdown Spectroscopy (LIBS), on the other hand, allows for the determination of the relative composition of most chemical species that may be present in a carbonate. It is a valuable technique for producing qualitative, and in some cases pseudo-quantitative, elemental chemical maps — including at high spatial resolution. Extracting information about a specific element from LIBS spectra is not straightforward and requires several steps: selecting and identifying one or more spectral lines per chemical element, followed by mathematical fitting. The data obtained from LIBS line fitting are not directly comparable to those from isotopic analysis, as the measurements are of different nature and correspond to distinct sampling modes (surface for LIBS, volume for isotopic analysis). Nevertheless, combining these two techniques can yield complementary information, for example, to assess the spatial homogeneity of the analyzed area. We therefore propose to combine high-resolution LIBS surface imaging with lower-resolution, fully optical isotopic cartographic analysis (sample preparation and analysis by laser [1]), in order to assess whether the combined approach can enrich the information obtained.

Keywords: High Resolution LIBS imagery, Laser-Laser isotopy, carbonate analysis, data fusion

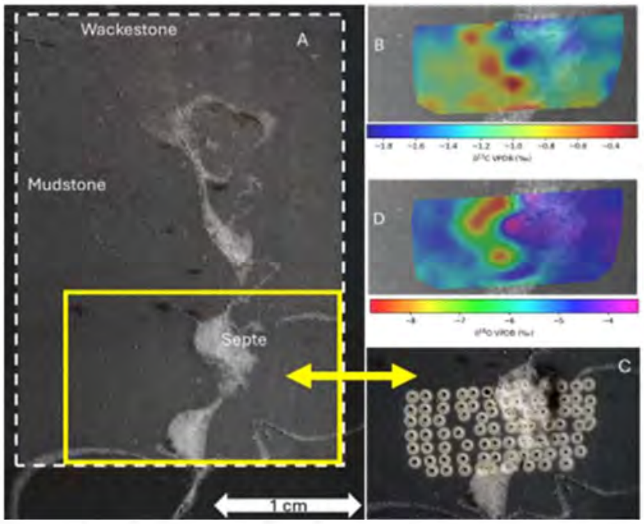

Fig. 1 Image of the sample after high-resolution LIBS analysis (dashed box in A); B & C: isotopic measurements of $\delta^{13}C$ and $\delta^{18}O$; C: view of the sample after laser-based isotopic analysis.

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I3

Laser-induced plasma and biosensing: coupling Laser-Induced Breakdown Spectroscopy with Lateral Flow Immunoassay

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In this work, Laser-Induced Breakdown Spectroscopy (LIBS) was coupled with Lateral Flow Immunoassays (LFIA) to directly probe plasma emission on LFIA test lines and quantify multiple biomarkers simultaneously. LFIA offers a rapid, easy-to-use platform for biomedical testing, while LIBS provides fast, multi-elemental analysis through laser-induced plasma.

The enhancement of LIBS sensitivity was obtained since metallic nanoparticles conjugated with detection antibodies were employed, thus plasma emission intensities increase because of the so-called nanoparticle-enhanced LIBS (NELIBS) effect [1,2].

The primary goal of this work was to investigate the characteristics and dynamics of laserinduced plasma on both LFIA control and test lines, focusing on the optimization of plasma parameters to maximize analyte detection. The work's specific objective was to identify and quantify exosomes, a subtype of extracellular vesicles (EVs) derived from blood samples. EVs are characterised by the presence of tetraspanin proteins on their membrane surfaces. Two distinct antibodies were conjugated with gold and silver nanoparticles to simultaneously detect and quantify the membrane-associated tetraspanins, enabling multiplex detection on a single test line. This study shows the power of integrating plasma spectroscopy with rapid immunoassays, for quantitative biosensing and diagnostics (Funded by the European Union - Next Generation EU, Mission 4 Component 1 CUPB53D2302546 0001)

Keywords: LIBS; LFIA; laser induced plasma; exosomes.

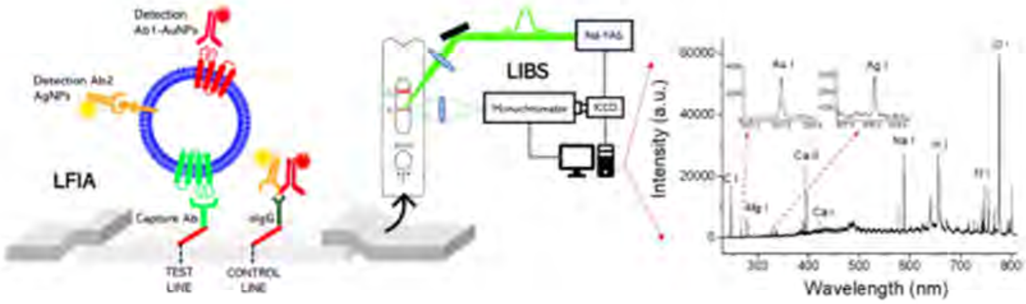

Fig. 1 LFIA-LIBS to simultaneously quantify different membrane proteins on an extracellular vesicle and plasma emission spectrum

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O17

Methodology for using portable LIBS in the field of occupational health

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Worker safety necessitates accurate and rapid assessment of exposure to airborne metal and metalloid aerosols. In occupational health monitoring, exposure is routinely quantified by collecting particulate matter onto specialized collection membranes over a defined sampling period [1]; this step concentrates the analytes, enabling the measurement of mass concentration against regulatory occupational exposure limits (OEL). However, common methods, typically involving sample acid digestion and ICP-OES analysis, are time-consuming and rely on expensive laboratory instruments, delaying workplace safety interventions [2]. Consequently, portable Laser-Induced Breakdown Spectroscopy (pLIBS) offers a field-deployable and efficient methodology for the rapid direct analysis of hazardous metals. In this study, this methodology was developed and optimized for the direct analysis of welding fumes collected on standard PVC collection membranes (Fig. 1, *left*). The research focused on mitigating common analytical challenges associated with using thin membranes by optimizing three critical parameters: mechanical pre-compression of support pad, commonly placed below the collection filter, for sample flatness; a minimal acquisition protocol to prevent particle displacement on the aerosol-loaded membrane; and the minimal operational shooting distance (z) for maximum plasma generation. The parameters were optimized for both virgin and aerosol-loaded membranes (Fig. 1, *middle and right*). The pLIBS system delivered excellent qualitative performance, by resolving primary emission lines for the key welding fume elements (Ni, Fe, Mn, Cr) with negligible spectral interference from the substrate. Ongoing and future work focuses on quantitative calibration, real-sample validation, and testing other standard filter media for broader occupational exposure monitoring.

Keywords: pLIBS, Aerosol, Metals, Occupational Health

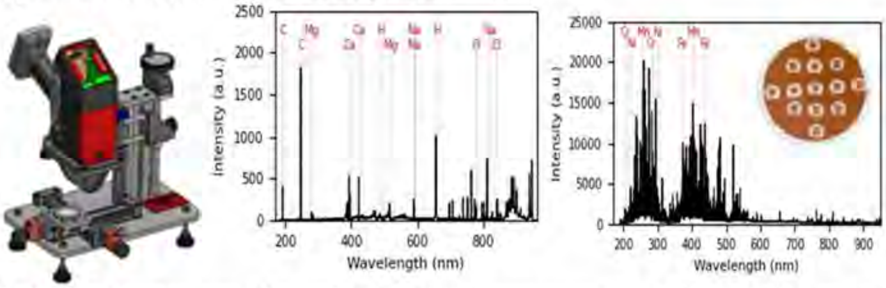

Fig. 1 (Left) Experimental setup for performing pLIBS measurements. (Middle) Typical spectrum of a PVC virgin membrane, showing its main emission lines. (Right) Typical spectrum of the shown PVC membrane loaded with welding fume aerosols tested by pLIBS, showing the main emission lines of welding fume elements.

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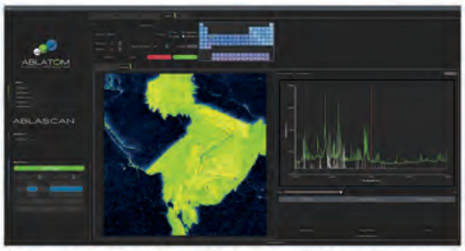

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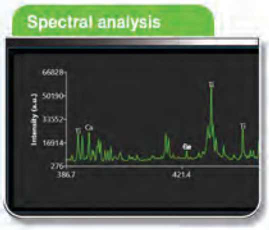

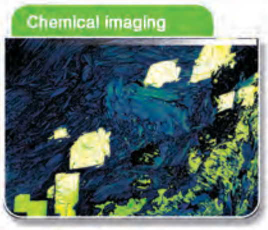

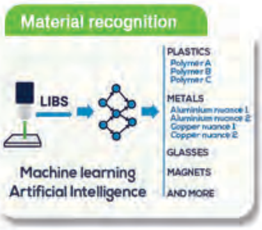

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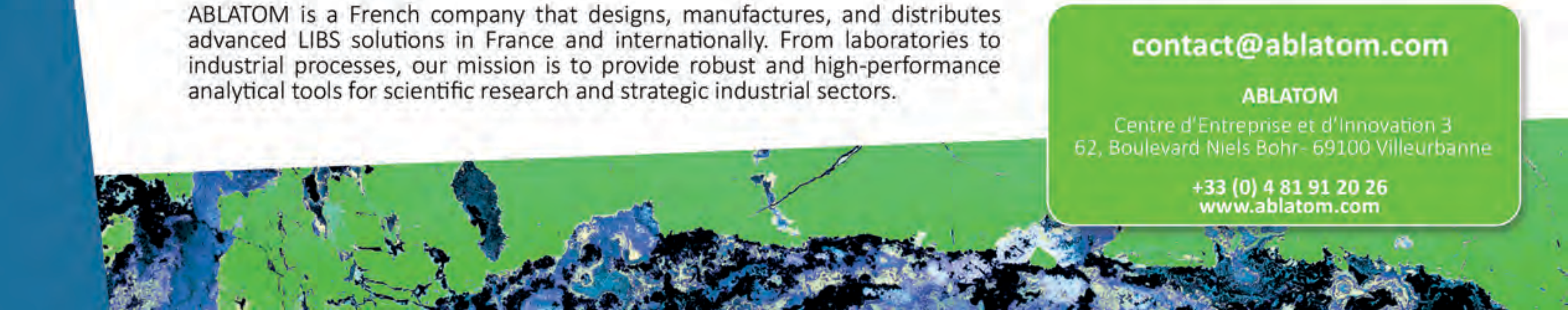

O18

Calibration-free Laser-induced Breakdown Spectroscopy (CF-LIBS): Screening of Human Lifestyle Using Fingernails

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Calibration-free Laser-induced Breakdown Spectroscopy (CF-LIBS) is a rapid, non-invasive analytical technique, making it particularly suitable for biomedical applications such as clinical screening [1]. Although blood samples are commonly used for clinical screening, they require an invasive procedure called venipuncture and are subject to short-term fluctuations, which makes them unsuitable for long-term health monitoring [2]. Fingernails overcome these limitations by assessing long-term health over several months due to their slow growth rate [3]. In this study, 40 fingernail samples were analysed alongside detailed participant data, including information on age, smoking habits, alcohol consumption, and diet. Using CF-LIBS, significant differences were identified by analysing characteristic intensity ratios such as K/C, Mg/C, and Ca/C. Lower Mg/C levels were observed in vegetarians and females, whereas individuals with alcoholism exhibited lower K/C levels than non-drinkers. Non-vegetarians exhibited greater nutritional accumulation than vegetarians. Non-smokers could be clearly differentiated from smokers, regardless of their smoking frequency.

Machine learning algorithms, specifically linear discriminant analysis (LDA) and Mixed Models, were applied to classify the groups and determine the influencing factors. These findings, based on lifestyle detection through elemental composition analysis, suggest that CF-LIBS can also be used to examine fingernails for signs of disease.

Keywords: CF-LIBS, Machine learning, Fingernails, Biomedical screening

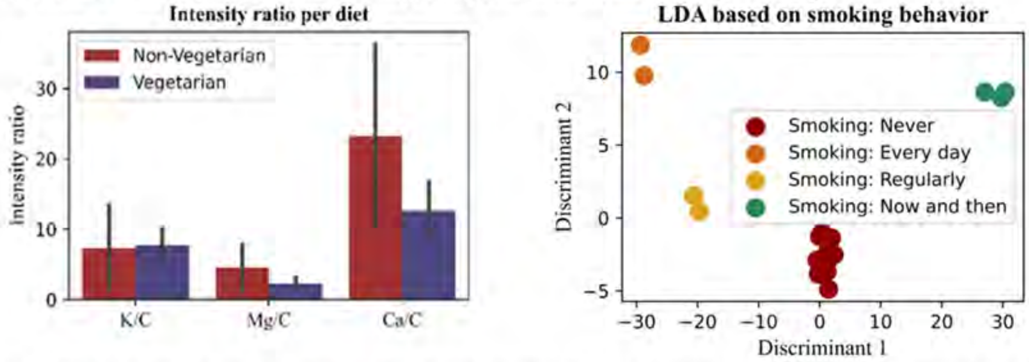

Fig. 1 The left figure shows the individual intensity ratios of K, Mg and Ca to C, for meat-eaters in red and vegetarians in blue. The right figure shows the LDA analysis used to classify smoking behaviour. N = 40.

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O19

Development of matrix-matched standards for LIBS Imaging

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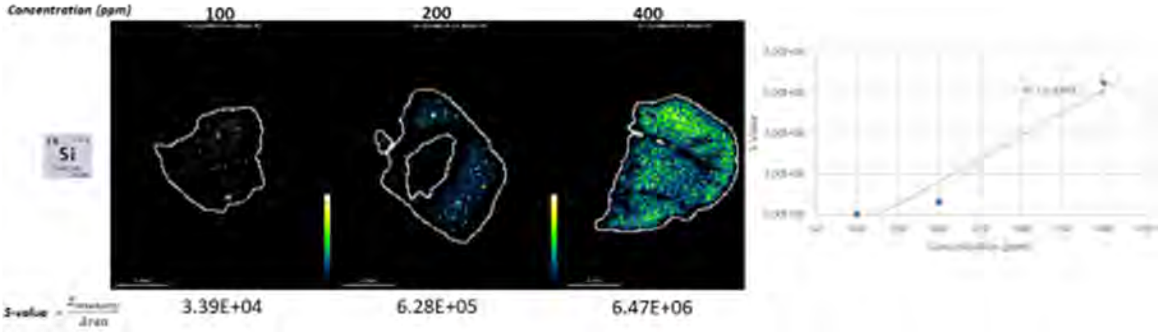
Over the past decade, laser-induced breakdown spectroscopy (LIBS) has emerged as a valuable technique for imaging and quantifying elements in biological samples [1]. Multiple metallic elements are known to be involved in pathological processes, including cancer, pulmonary diseases and metal overexposure-related conditions. LIBS imaging can provide a map of elemental distribution in any type of biological tissue at a resolution of a few micrometers. However, the development of matrix-matched standards is needed to move towards quantitative LIBS imaging.

In Grenoble Hospital (France), we image the elemental content of real patient biopsies with a unique biomedical LIBS microscope (ELM-XS-MED, from ABLATOM SAS). In the aim of working quantitatively, we are developing our own multi-elemental matrix-matched standards in formalin-fixed, paraffin-embedded tissues (FFPE). Our innovative approach involves a multistep passive impregnation of animal organs with metal-rich solutions. Starting from single element standards in entire organs, we improved our process towards the development of multi metal standards in 3 mm diameter organ cylinders. We used the S-value metric [2] for quantitative assessment of the elemental content of our calibrators. This enables us to compare samples from different experiments and construct quantitative calibration curves. Ongoing work focuses on generating multi-elemental standards for various tissue type, impregnated with several carcinogenic elements (Be, Cd, Cr, Si and Ti).



Caption: The results show the effective impregnation of liver samples with different silicon concentrations. We used the 288.1 nm emission line for Si quantitation. The S-values (Si) are correlated to Si concentration in solution. However, in this example, the calibration curve was not fully linear ($R^2 = 0.93$).

Overall, this pioneering work generated the first matrix-matched standards for LIBS imaging applied to biological tissues. It paves the way for future quantitative LIBS bioimaging in biology, toxicology and medicine, especially to support the diagnosis of various pathologies related to metal exposure.

Keywords: Biology; Medical; Diagnostic; Calibration

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I4

Temperature determination of laser-induced plasma in water

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Temperature determination of laser-induced plasma generated in water is of great importance for a better understanding of underwater laser-induced breakdown spectroscopy (LIBS) as well as other underwater plasma-based techniques. In this work, we measured the temperature of underwater plasma by using optical emission spectroscopy. The temperature was calculated respectively from the SahaBoltzmann plot of Ca I 422.67 nm, Ca II 393.37 nm, and Ca II 396.85 nm lines, and from the OH molecular band $A^2\Sigma^+{-}X^2\Pi$ around 310 nm. It shows that in the time window from 75 ns to 700 ns, the Saha-Boltzmann temperature decreases from 12700 K to 7700 K, which is significantly higher than the molecular temperature that decreases from 11000 K to 4100 K. To verify these temperature values, shadowgraph images of the early-stage cavitation bubble were taken and the bubble temperatures were calculated based on the bubble adiabatic expansion model. The plasma, bubble and OH molecular spectra results are shown in Fig. 1. We find that the OH molecular apparent temperature is compatible with the cavitation bubble temperature, whereas the Saha-Boltzmann apparent temperature turns out to be higher. The present results in this work provide suggestions in measuring the underwater plasma temperature, and also give a link between the plasma properties and the cavitation bubble dynamics for the laser-induced breakdown in liquids.

Keywords: Laser-induced plasma; Plasma temperature; OH molecular emission; Bubble dynamics.

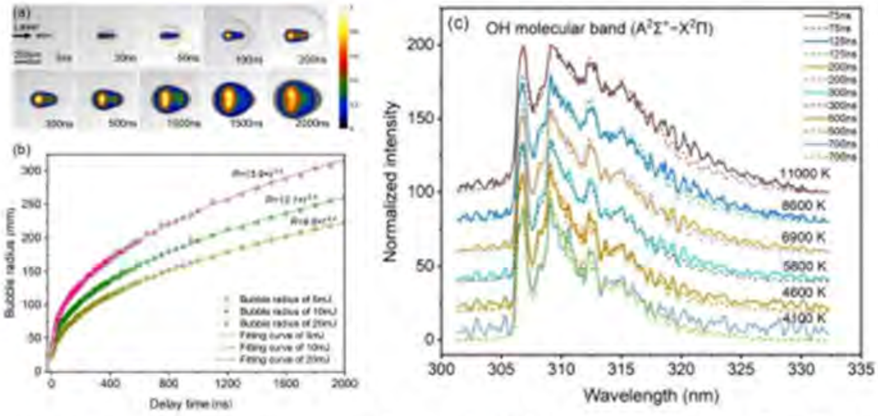

Fig. 1 (a) Composite images of plasma emission and cavitation bubble at the stage before 2 µs. Each plasma image was an average of 50 laser shots and was normalized with its maximum emission intensity. (b) Bubble radius as a function of delay with the laser energies of 5, 10, and 20 mJ. The bubble radius R as a function of time t can be well fitted by $R=at^{0.4}$, and a is a constant which is dependent on the laser energy. (c) Plasma emission spectra of OH molecular band ($A^2\Sigma^+{-}X^2\Pi$) recorded at different delays from 75 to 700 ns. The temperatures were obtained by fitting the experimental spectra with synthetic spectra using the LIFBASE software.

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O20

Overview of the Mars2020 mission and main results from SuperCam

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The Perseverance rover landed on Mars, at Jezero Crater, in February 2021. The rover carries SuperCam [1,2], which is the second instrument using the LIBS technique for planetary science. As a heritage from the ChemCam instrument onboard the MSL/Curiosity rover [3,4], SuperCam not only uses the LIBS technique, but also four other techniques (see Figure 1.A): two vibrational spectroscopic techniques (Raman and the VISIR spectroscopies) in order to get information about the mineralogical and molecular composition of targets; a microphone, to study the atmospheric properties of Mars, as well as to get some information concerning the rock hardness when used in combination with the LIBS; a color camera in order to visualize the point analyses performed on each target of interest.

Since February 2021, the rover has driven more than 39 km and several parts of the Jezero crater have been explored: the crater floor, the delta front and top, the margin unit with Neretva Vallis, and is now exploring the crater rim (see Figure 1.B). SuperCam has analyzed more than 1000 targets using the LIBS technique, representing more than 320 000 laser shots (i.e., individual spectra).

We will present an overview of the main findings from SuperCam, as well as highlight the key role of the LIBS technique in this mission, to help characterize the geological settings of the samples to collect for potential Earth return, and also how the synergy with the other spectroscopic techniques is of particular importance for planetary science.

Keywords:

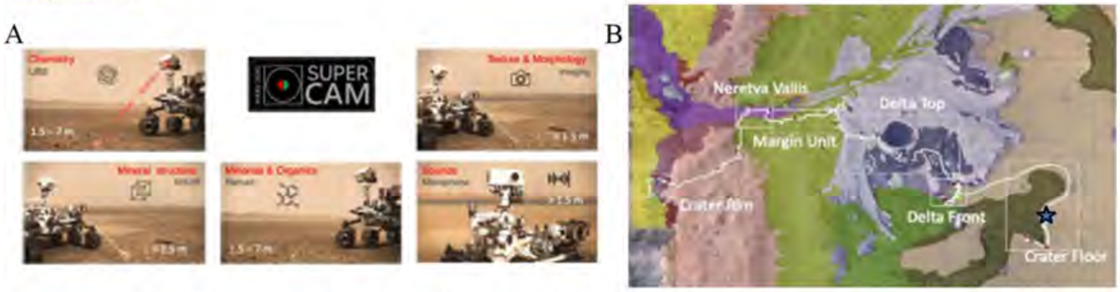

Figure 1: A. Overview of the five techniques used by SuperCam. This Figure is extracted from [1]. B. Overview of the traverse performed by Perseverance since landing (blue star). The traverse corresponds to the white path. Each location of interest is highlighted and samples are shown in red crosses. Actual location of the rover is shown as the cyan dot.

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O21

LIBS in airless environments: from the lab to the Moon and beyond

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The Chandrayaan 3 (C3) mission developed by the Indian Space and Research Organization (ISRO) is the first mission carrying a LIBS instrument for ground in situ measurement on the Moon. The rover worked during 14 Earth days allowing it to complete a 100-meter traverse and 66 LIBS investigations gathering around 740 spectra [1]. After removing inconsistent data and degraded spectra, only 34 investigations could be used for science leading to 133 measurement spectra. Their analysis reveals that 12 of these investigations contain quality spectra i.e., high Signal-to-Noise Ratio with low noise. Spectra from these best investigations were also studied in detail using peak fitting and element identification. When comparing our results with those initially published in [1], we found an irregular wavelength shift throughout the spectra, which we suspect may lead to elemental peaks misidentification. We propose our own identification in Figure 1 (left).

Focus issues could explain C3's anomalies, then we studied the effect of laser focus under vacuum conditions. Series of laser shots with varying focus were performed on silicon and titanium samples with the laboratory model of ChemCam at IRAP, Toulouse, France. The results on silicon for instance indicate that the intensity of its main emission peak (at 288 nm) is divided by 2 at ± 20 mm from the best focus position at 1.6 m from the target, and ± 30 mm at 3 m focus. Knowing that the C3's LIBS instrument had a fixed focus distance at 20 cm, our results suggest that only a few millimeters away from the best focus position during measurements would cause the signal to collapse.

With this in mind, and based on the heritage of ChemCam [2,3] and SuperCam [4,5], CNES and IRAP, in partnership with LANL and DLR, are developing microLIBS (Figure 1, right), a new generation of LIBS instrument for planetary exploration including the Moon and airless bodies [6]. This instrument will include a focusing and targeting system to perform LIBS analyses in the distance as micro-maps on < 1 cm² areas in one hour. Spectrometers will detect both major and minor elements and in particular volatiles, and further work is now required to investigate the effect of focus on quantification.

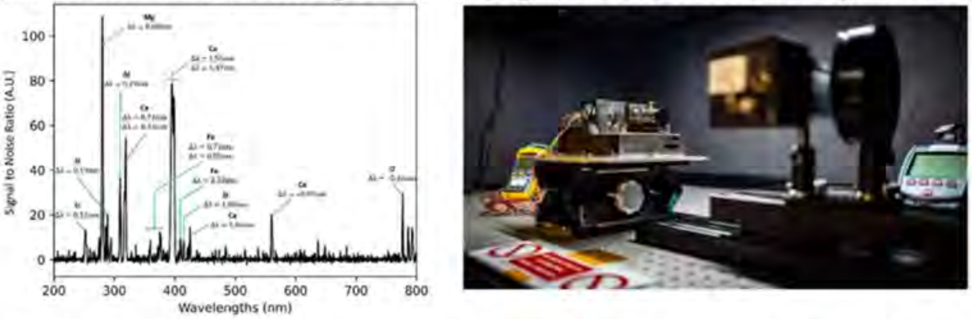

Fig. 1 Left : a LIBS spectrum from C3's data from one of the best 12 investigations, $\Delta\lambda=\lambda \quad -\lambda$
Right : microLIBS prototype on the optical bench (image from CNES).

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O22

Elemental sulphur deposit and its related enrichments as viewed by Chemcam.

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Here we characterize the first detections by ChemCam of native sulphur found in float rocks in the Gediz Vallis channel in Gale Crater, Mars, and we document sub-millimetre heterogeneities within the deposit and associated rocks. ChemCam is an active remote sensing instrument suite that has operated successfully on the Curiosity rover since landing on Aug. 6th, 2012 [1,2]. It uses laser pulses to remove dust and to profile through weathering coatings of rocks up to 7 m away. Laser-induced breakdown spectroscopy (LIBS) obtains emission spectra of materials ablated from the samples in electronically excited states. Gediz Vallis (GV) is a narrow canyon on the flank of Aeolis Mons that drains a catchment of about 127 km^2 and leads to a 900 m wide, 120 m deep canyon that curves and terminates abruptly [3]. It cuts a stepped surface, and broad, shallow flat-floored canyons that terminate in a deeply etched yardang unit [4]. In GV, a triangular area, probably resulting from the exhumation of channel fill deposits, show the presence of numerous allochthonous light-toned blocks forming a talus. The overlying material just above those blocks and at the bases of large bedrock blocks is a light-toned nodular strata. Further south above the deposit, at the edges of these large blocks, light-toned halos have also been observed. Among all these light-toned blocks, thirteen have been analysed by ChemCam. They are generally characterized by a cottony and fluffy texture, and their average LIBS spectra of these targets exhibit all the theoretical lines of sulphur up to the fourth excitation state, indicating an almost pure phase [5]. This is confirmed by the fact that in shot-to-shot spectra, no other element shows emission lines, except in the first five shots that sample the dust cover. However, some contamination can be observed in some points that are generally located on holes or small fractures. But in these rare cases, the sulphur signal is always anti-correlated with the signal of those other elements, supporting that sulphur is a distinct and pure phase This applies also to minor and traces elements like Li, Ba, Sr or Rb. On Earth, sulphur is commonly associated with chalcophile elements (As, Cu, Ni, Cs, Co, Zn, Ga, …) that concentrate in sulphides during partial melting of the mantle by sulphur immiscibility [6]. None of the main chalcophile elements were identified in our LIBS spectra, at least at the ChemCam sensitivity. Indeed, all the emission lines can be explained by a sulphur line up to SIV. Finally, the sulphur spectra are characterized by the complete absence of hydrogen, chlorine or fluorine. The oxygen signal is also low and decreases with the sulphur signal in the shot-to-shot data. All these observations mean that the pure sulphur is highly reduced. The composition of these blocks is compatible with pure native sulphur. No other elements are correlated with sulphur and notably no chalcophile elements are detected, which indicates that the sulphur unlikely originated by the fusion of a deep mantle source. A regional metamorphic process leading to the deposition of sulfosalts formed in a closed system, like in the Alps [7], seems also unlikely. An impact derived molten sulphur lava flow that fills a pool is envisaged. The overlying strata and especially the bright halos exhibit also sulphur enrichments.

Keywords: Mars; ChemCam; Sulphur

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O23

Investigation of Uranium Emission Lines for Isotopic Analysis by Laser-Induced Breakdown Spectroscopy (LIBS)

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In the context of nuclear dismantling and waste management, rapid and in-situ analytical methods are required to characterize uranium at low concentrations for mapping and surface contamination assessments. Laboratory elemental analysis techniques, although precise, are time-consuming and not suitable for on-site applications. Laser-Induced Breakdown Spectroscopy (LIBS) offers a promising alternative thanks to its speed, minimal sample preparation, and potential for isotopic analysis. While LIBS is primarily used for elemental characterization, studies have shown that isotopic discrimination is achievable for several light and heavy elements, such as lithium, and uranium [1], [2]. The purpose is to provide a foundation for the development of deployable LIBS-based isotopic measurement systems for nuclear industry applications.

Although the uranium line at 424.43 nm is widely studied for isotopic discrimination, it suffers from low SNR ratio. The goal is to identify other uranium lines for $^{238}U/^{235}U$ isotopic analysis. We aim to determine the lines with strong isotope shifts.

A combined experimental and theoretical approach was implemented to select shifted transition lines with limited spectral interference, maximal SNR. Using published spectroscopic databases on uranium lines we compiled a database on isotope shift. A theoretical study was also carried out to evaluate the feasibility of predicting uranium isotope shifts. Several candidate lines were identified beyond the well-known transitions, showing favorable properties for isotopic discrimination.

The second phase involves experimental LIBS measurements that are conducted on uranium oxide pellets of different isotopic composition. The emission spectra are recorded with a high-resolution spectrometer to identify the most favorable measurement conditions for isotope discrimination and quantification in 1 atm air, similar to conditions encountered for in situ applications. Results confirm that several of the theoretically predicted lines, rarely or never reported in previous isotopic LIBS studies, exhibit measurable isotopic effects and appear highly promising for future quantitative analyses.

Keywords: LIBS; isotopic; uranium; spectroscopy;

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O24

LIBS for fusion: tungsten and boron spectral characterization

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This communication explores the use of CF-LIBS (Calibration-Free Laser-Induced Breakdown Spectroscopy) for analyzing the inner walls of ITER. The application of this method requires prior knowledge of the emission spectra associated with the main constituent elements of the tokamak reactor walls, principally tungsten (W) and boron (B). The difficulties in interpreting the tungsten spectrum are due to the very large number of transitions associated with this species, while for boron, the challenge lies in the lack of detailed spectroscopic studies on this element. This method also requires the emitting medium to be in local thermodynamic equilibrium (LTE) to allow for the determination of the composition of the laser-induced plasma, either through the construction of Saha-Boltzmann plots or by calculating the emission spectrum using a radiative transfer code [1,2].

In this communication, the results associated with measurements on tungsten carbide (WC) and boron carbide (B4C) samples, performed under standard experimental conditions in a helium atmosphere at different pressure levels (50 Pa, 500 Pa, 50 000 Pa), are presented. An Nd:YAG laser source was used, with a repetition rate of 10 Hz and a pulse duration of 4 ns. The energy delivered per pulse is $E_L = (15 \pm 0.5)$ mJ, with an average irradiance on the sample of $\varphi_L = (4.27 \pm 0.22) \times 10^{14}\ \mathrm{W.m^{-2}}$. The spectra were acquired using an Echelle broadband spectrometer. The electron density and temperature of the emitting medium were measured using the acquired emission spectra, and the acquisition conditions necessary to observe a laser-induced plasma in local thermodynamic equilibrium (LTE) for CF-LIBS measurements were identified by comparing the experimental calibrated emission spectra with those resulting from the implementation of the MERLIN code, an adaptative LTE radiative transfer model (Fig. 1) [2]. Finally, new spectroscopic parameters (ω_{ki} and A_{ki}) for W I-II lines were obtained from MERLIN calculations.

Keywords: Fusion; Tungsten; Boron; Calibration-Free LIBS

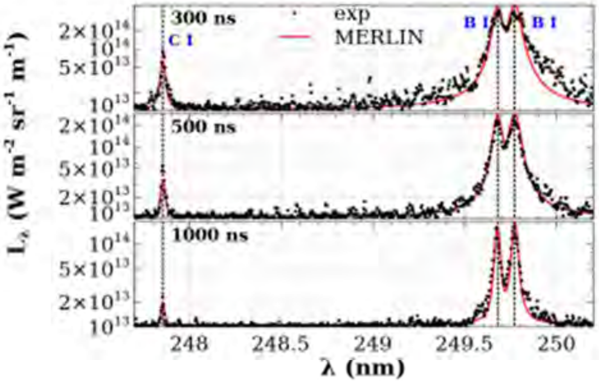

Fig. 1 Experimental boron emission spectra compared with LTE spectra calculated using the MERLIN code.

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DAY 3

WEDNESDAY | 28TH JANUARY

09:00 | SESSION 7: FUNDAMENTAL 1 *CHAIRS: ALESSANDRO DE GIACOMO / MARCOS LÓPEZ*

- **09:00** | **KEYNOTE 3: Roberta Fantoni** *LIBS applications in local and remote characterization of cultural heritage materials*
- **09:45** | **INVITED 5: Arnaud Bultel** *How the modelling can contribute to a better understanding of the underlying physics of LIBS*
- **10:15** | **Oral 25 - Ivan Urbina** *Laser induced plasma evolution process recorded by shadowgraph in levitated droplets*
- **10:30** | **Sponsor 3: OPTON LASER (Alex Delhomme)** *High energy diode-pumped lasers for LIBS*
- **10:45** | **Oral 26 - Veis Pavel** *Impact of Spectral Averaging on Precision and Depth Resolution in CF LIBS for JET Divertor Tiles*

11:00 | COFFEE BREAK

11:30 | SESSION 8: ENVIRONMENTAL AND GEOLOGICAL SCIENCES *CHAIRS: ALFRED VOGEL / ALEXANDRE CHERRIER*

- **11:30** | **INVITED 6: Cécile Fabre** *From Handheld LIBS Analysis to µLIBS High-Resolution Imaging*
- **12:00** | **Oral 27 - Jorge Caceres** *Hybrid Pollution in the Air – Polymeric and Metallic Signatures of Microplastics*
- **12:15** | **Oral 28 - Pedro Jorge** *Automated Detection of Contaminated Wood Waste Using Computer Vision and LIBS*
- **12:30** | **Oral 29 - Ruixue Wang** *Rapid and Scalable LIBS–ML Workflow for Quantitative Mineral Mapping*
- **12:45** | **Oral 30 - Ben Van Der Hoek** *Downhole LIBS sensor: in-situ analysis of mining drill holes*
- **13:00** | **Oral 31 - Nilvan Silva** *Nanostructured substrate produced by CO2 laser photothermal treatment*

13:15 | LUNCH

14:30 | PROCESSING / INDUSTRY (CONT.) *CHARIS: TIAN YE/EDITH BÖHMER*

- **14:30 | INVITED 7: Ludovic Duponchel** *Exploring LIBS imaging at scale: how chemometrics changes what we can see*

- **15:00 | Oral 32 - Yuanzhi Cai** *Spatially Aware Refinement of LIBS Mineral Maps with Conditional Random Fields*

- **15:15 | Oral 33 - Kristin Rammelkamp** *Investigating Depth Trends in ChemCam LIBS Data with Tensor Component Analysis*

- **15:30 | Sponsor 4: AVANTES (Martijn van de Goor)** *New Possibilities in LIBS Enabled by Avantes Spectrometer Technology*

- **15:45 | Oral 34 - Lukas Retterath** *Rapid Hardness Characterization of Steel via Femtosecond Laser-Induced Plasma Spectroscopy*

- **16:00 | Oral 35 - Kristjan Leosson** *Application of molten-metal LIBS in the aluminum industry*

- **16:15 | Oral 36 - Lina Jolivet** *Feasibility of Hydrogen Quantification in Metals by Laser-Induced Breakdown Spectroscopy*

16:30 | COFFEE BREAK

17:00 | SESSION 10: INSTRUMENTATION 2 *CHAIRS: MARCELLA DELL'AGLIO / NICOLAS HERREYRE*

- **17:00 | INVITED 8: Jhanis Gonzalez** *Innovative Advances in LIBS: Enhancing Sensitivity, Precision, and Applications*

- **17:30 | Oral 37 - Erik Wüst** *Depth-resolved picosecond LIBS of deuterium retention in self-damaged tungsten*

- **17:45 | Oral 38 - Rongxing Yi** *In-situ Residual Hydrogen Isotope Analysis*

- **18:00 | Oral 39 - Dávid Jenő Palásti** *Utilizing modern fiber lasers for LIBS*

- **18:15 | Oral 40 - César Alvarez** *Multimodal hyperspectral imaging for interpretation of optically active centers*

- **18:30 | Oral 41 - Simon Blume** *Femtosecond vs. Nanosecond Laser-Induced XUV Spectroscopy (LIXS)*

K3

LIBS applications in local and remote characterization of cultural heritage materials

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Optical technologies, within which laser spectroscopies currently play an important role, are nowadays widely used in cultural heritage due to the non destructive nature. The applications include material recognition for documentation and conservation. To this respect LIBS analysis acceptance was more difficult, since its micro-destructive effects onto surface and subsurface layers. However, the possibility to perform true multi-elemental analysis, including light elements, and highly resolved stratigraphy on multilayered materials, supported the use of LIBS whenever such information was required, especially in the case of decorated heterogenous original materials or degraded surfaces [1]. Another peculiarity of LIBS utilization relevant to cultural heritage is the capability to perform in situ and remote material characterization, as for instance on monuments' surfaces [2], as well as to be applied underwater, which is important for submerged archaeological sites.

In this paper we review LIBS applications, qualitative/semi-quantitative analysis and stratigraphy applied on different materials regarding cultural heritage carried out at ENEA Frascati laboratory in the frame of former Regional, National and International projects; the experiments include stand-of and underwater measurements. The activity required former studies on multilayered mock-ups, addressed to demonstrate the LIBS performances in terms of concentration of different species and resolution in depth, an example from ref [3] is reported in fig. 1. Proper normalization and calibration techniques have been developed and utilized in order to obtain quantitative information on the subsurface layers. Among the considered surfaces there are archaeologic ceramics (Roman, Medieval Italic, Pre-Colombian) metals (e.g. bronze artifacts and coins), classic marbles, pigments in oil paintings and frescoes.

Keywords: LIBS stratigraphy, remote LIBS, multilayered cultural heritage, decorated surfaces

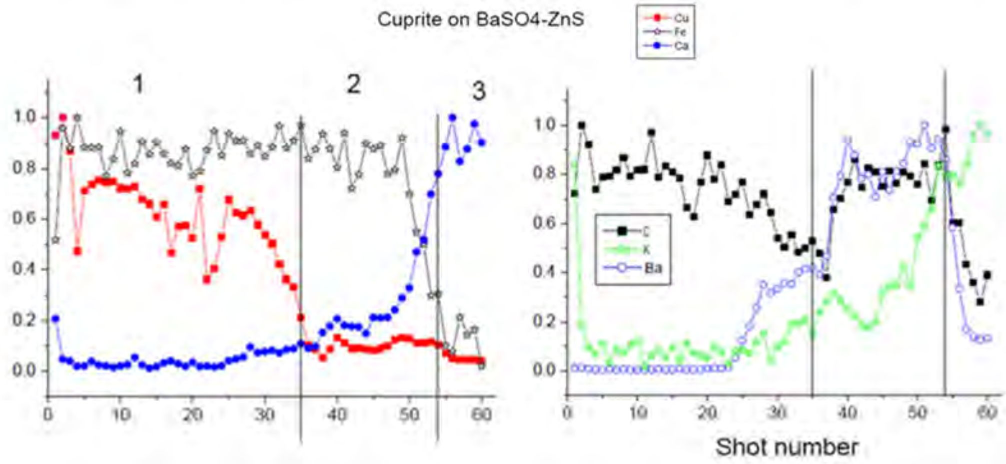

Fig. 1 Stratigraphy on different elements characteristic of a multilayered mockup with cuprite and green earth

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I5

How the modelling can contribute to a better understanding of the underlying physics of LIBS

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LIBS diagnostic is fundamentally based on the discriminant spectroscopic analysis of light produced by a plasma induced by a laser pulse focused onto the sample under study. This diagnostic approach therefore relies on laser-matter interaction and on the radiative properties of the induced plasma.

Two methods are used to implement this diagnostic: one based on the existence of calibrated samples, allowing the sample composition to be determined by comparison; the other based on obtaining a plasma at thermodynamic equilibrium, whose properties can then be fully calculated, particularly its spectrum. The second method is called CF LIBS, for Calibration-Free LIBS. The first method is often used when there is doubt about the existence of equilibrium. Thus, thermodynamic equilibrium constitutes a kind of pivotal situation that dictates how signal processing must be carried out to determine the sample composition.

The question of equilibrium is central to plasma physics: this is why criteria for achieving it were identified as early as the 1960s, initially for other types of plasmas. The best known is the McWhirter criterion, which stipulates that the plasma's electron density must exceed a certain threshold to ensure that collisions play a dominant role over radiation in the depopulation of excited states. These older criteria are based on simplifying assumptions: the plasma is optically thin and quasi-steady, only allowed transitions are considered, and the hydrogen-like assumption is made for the expression of de-excitation rates.

Advances in modeling allow us to view these criteria in a new light, particularly specifically in the case of laser-induced plasmas produced during LIBS diagnostics. They rely on the development of unsteady collisional-radiative models coupled to transport resulting from expansion and radiative transfer. In this presentation, a reference model will be presented for several types of metallic atoms and the results will be analyzed in detail in order to discuss these criteria.

O25

Laser induced plasma evolution process recorded by shadowgraph in levitated droplets.

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Laser induced break down spectroscopy assisted by acoustic levitation system (LIBS-AL) is technique which has shown promising result to analyses liquids sample avoiding contamination from human manipulation. On previous publication, it was demonstrated the capabilities of LIBS-AL for analytical determination of boron (B) using calibration curve by external standard (CC) [1] and Calibration Free for detection of alkaline metals in mineral waters solution [2]. Nevertheless, the influence of the plasma expansion on those methods has not been studied in the deepest manner. To provide more information about these phenomena and the influence in analytical methods, the plasma expansion has been recorded with a shadowgraph and fast-photo set-up which was added to the common LIBS-AL experimental arrangement [2]. The temporal evolution of plasma formation was recorded as well. Different focal distance, ablation position and droplet sizes were considered to describe the phenome. The experimental results suggest difference in the ablated material depending on time. Furthermore, it has been quantified the effective mass ablated depending on the droplet size, fluence, and delay time. Figure 1 shows some images recording in the LIBS-AL.

Keywords: LIBS-AL; shadowgraph, plasma expansion.

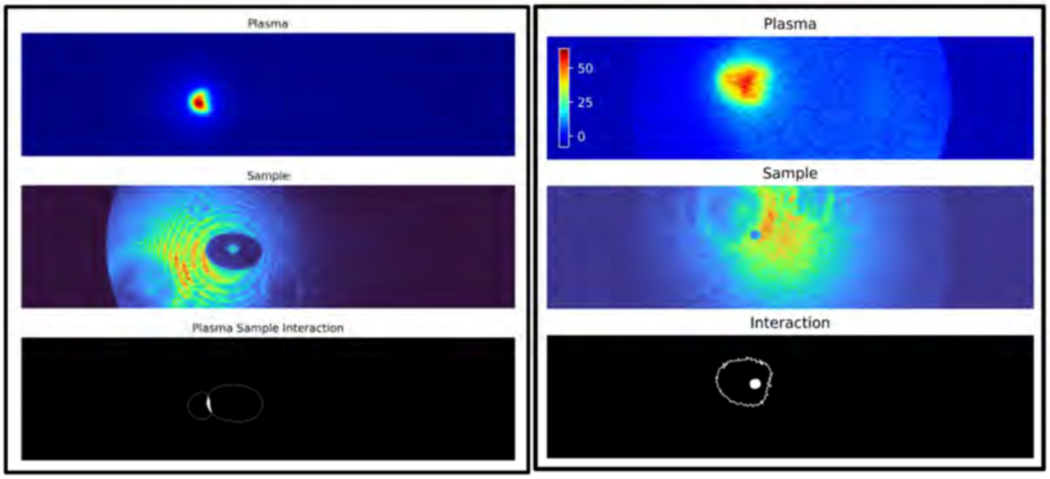

Fig. 1 – Shadowgraph and fast photo of the droplet ablated to DT=1000ns. Left- size:15µL, right – size 0.3µL.

ACKNOWLEDMENT

The authors acknowledge the financial support from VEGA (1/0815/25, 2/0120/25), APVV (22-0548, 23-0281), and GUK/1115/2025.

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O26

Impact of Spectral Averaging on Precision and Depth Resolution in CF LIBS for JET Divertor Tiles

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R. Rayaprolu[e], R. Yi[e], N. Jones[f], W. Gromelski[g], J. Butikova[h], T. Dittmar[e], M. Sackers[e],
E. Wüst[e], A. Hakola[d], S. Brezinsek[e,i] , UKAEA RACE Team

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Laser Induced Breakdown Spectroscopy (LIBS) has become a key diagnostic tool for examining plasma facing components (PFCs) in fusion environments [1]. During plasma operation, processes such as erosion, transport, redeposition, and fuel retention give rise to complex multi-elemental layers containing Be, W, Mo, H, D, T isotopes, along with various impurities including Ti, Ni, Cr, C, and O [2], [3]. Precise characterization of these layers is crucial for understanding material migration, surface chemistry, and fuel retention, which are central to the safety and performance of ITER and future fusion devices. In this work, we analyze in-situ LIBS measurements obtained with the JET robotic wall inspection system following the recent D, T campaigns. These data are used to derive quantitative depth profiles of the wall composition, covering both major and minor species as well as retaining hydrogen isotopes. Details of the experimental setup can be found in Refs. [4], [5], [6]. Quantitative analysis is performed using the well-established Calibration Free LIBS (CF LIBS) methodology [7], [8] for main elements (W I-II, Mo I-II, Be I-II, Ti I-II, Ni I-II, Cr I-II) without self-absorbed lines and lines with low transition probability. CF LIBS requires spectral averaging to suppress noise; however, the amount of averaging directly affects the attainable depth resolution. Minimal averaging is advantageous for determining major elements, as it preserves finer depth information. In contrast, identifying minor elements often requires more extensive averaging to reveal weak spectral features, at the cost of reduced depth resolution. In this work, we study the signal-to-noise ratio (SNR) with different averaging (rolling windows and spectral averaging) and how different window sizes affect the SNR. The aim of this contribution is to systematically assess how different levels of spectral averaging, from zero averaging upward, impact depth resolution in quantitative CF LIBS. This case study focuses on selected inner divertor tiles.

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I6

From Handheld LIBS Analysis to µLIBS High-Resolution Imaging: Applications in Sulfosalt Mineral Characterization

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In this study, we examine how LIBS can support the identification of minerals whose macroscopic recognition in the field is particularly challenging. Focusing on copper sulfosalt minerals with closely similar Cu-Fe-Sb–As–Cu contents (solid-solution series), including tetrahedrite and tennantite that may host trace elements such as Bi and Ag, we aim to highlight the value of rapid handheld LIBS analyses for optimizing field sampling strategies and for detecting elements that may penalize ore processing (notably arsenic).

The metallogenic relevance of these minerals relies on the ability to identify economically significant elements (Cu–Zn–Sb) hosted in mineral phases that remain poorly characterized. To assist geologists in reconstructing the chronological sequence of paragenetic events, µLIBS imaging provides crucial insights into mineral growth histories.

Initial high-spatial-resolution µLIBS investigations (1–2 µm) conducted on the same samples (Fig. 1) demonstrate that this technique now achieves a performance level comparable to that of electron microprobe analysis.

Keywords: handheld LIBS; µLIBS imaging; geology

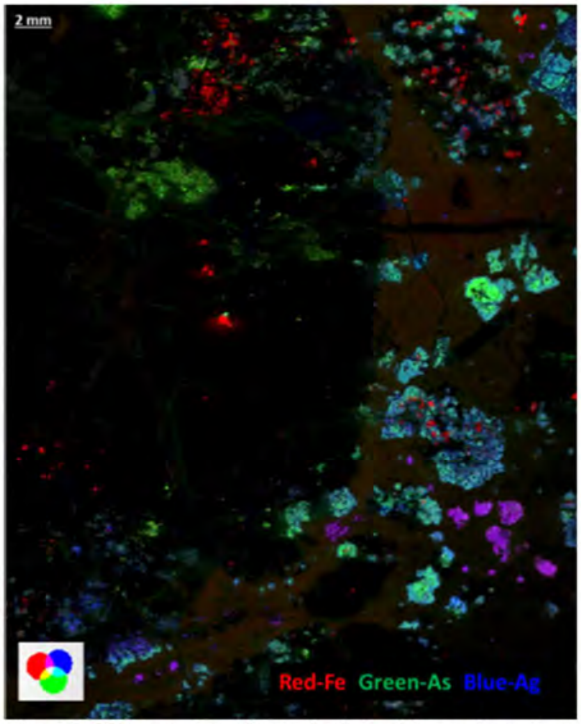

Fig. 1 LIBS imaging of tetrahedrite thin rock section

O27

Hybrid Pollution in the Air – Polymeric and Metallic Signatures of Microplastics in Madrid's Atmosphere

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This research presents the composition and identification of airborne microplastics (MPs), which are increasingly recognized as hybrid pollutants that can carry toxic trace metals through urban air. Using laser-induced breakdown spectroscopy (LIBS), an integrated approach is obtained that preserves spatial context and morphology while linking polymeric carriers to metal signals. The core analytical layer, laser-induced breakdown spectroscopy (LIBS), was configured for particle-scale mapping of key metallic fingerprints (e.g., Cu, Zn, Cr, Pb, Ni) colocated with MPs on the filter surface, enabling source-relevant interpretation consistent with non-exhaust traffic emissions and urban resuspension.

The study was conducted in Madrid across three representative environments: Aguirre School (a traffic-influenced urban area), the Chemistry Faculty site at UCM (an urban background), and Torremocha del Jarama (a peri-urban area). Optical microscopy under visible/UV illumination provided rapid enumeration and morphology screening of putative MPs directly on quartz filters revealing clear site-dependent contrasts with higher particle densities at the traffic-influenced site and lower densities at the peri-urban location, as well as a dominance of fibers over fragments. The study demonstrates a practical pathway for high-throughput metal screening on airborne MPs, with optical counts guiding LIBS targeting and Raman providing molecular confirmation where feasible. Our results underline the need to consider MPs as multipollutant vectors in air-quality assessments and offer a flexible platform for future quantitative coupling of particle-resolved LIBS mapping with bulk measurements and trajectory analyses.

Keywords:

Airborne microplastics; Trace metals; Hybrid pollutants; Vehicular emissions; Urban air pollution; Human health risk; Optical microscopy; Raman spectroscopy; LIBS; ICP-MS.

O28

Automated Detection of Contaminated Wood Waste Using Computer Vision and LIBS

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Rapid detection of chemical contaminants in wood waste is crucial to ensure safe and efficient recycling processes. Conventional laboratory-based techniques, such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS), require extensive sample preparation, long analysis times, and high costs, making them impractical for large-scale analysis and high turn-over rates.

In this work, we present an automated inspection system that combines computer vision and LIBS for dynamic analysis of wood materials on a conveyor belt under simulated industrial conditions. A YOLOv11-based vision model [1] performs real-time detection and segmentation of wood pieces, and a gantry-mounted pulsed laser is guided to acquire LIBS spectra from the moving samples. The integrated analysis pipeline processes the spectra in real time, enabling the identification of contaminant elements such as As, Ba, Cd, Cr, Cu, Hg, Pb, Sb, and Ti [2].

The system supports multiple operational modes depending on material density and flow characteristics, including targeted tracking of individual pieces, continuous scanning, and detailed compositional mapping for localized analysis. This integrated approach demonstrates a robust, scalable, and cost-effective solution for online or at-line identification of treated or contaminated wood, contributing to safer and more sustainable recycling practices.

Keywords: Wood Waste, Laser-induced Breakdown Spectroscopy, Machine Vision, Automated Heavy Metal Detection

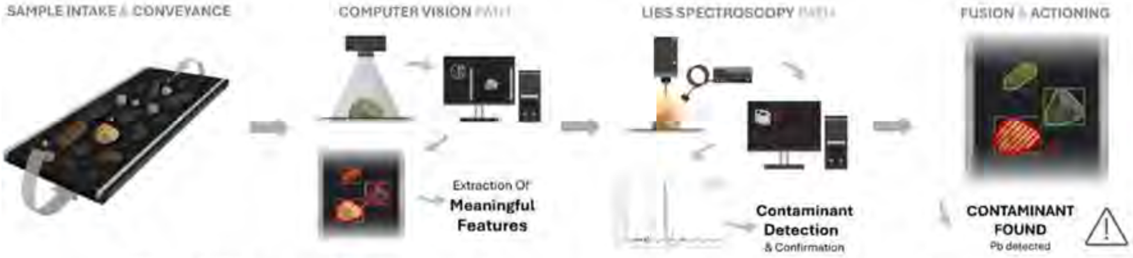

Fig. 1 LIBS assisted by Computer Vision workflow for real-time contaminant detection.

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ACKNOWLEDGEMENTS

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O29

Rapid and Scalable LIBS–ML Workflow for Quantitative Mineral Mapping Across Diverse Ore Systems

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Laser-Induced Breakdown Spectroscopy (LIBS) provides rapid, in-situ chemical imaging across a wide range of geological materials, yet its broader adoption in ore characterization has been limited by challenges in data handling and quantification. Here we present a scalable LIBS–ML workflow developed at CSIRO that enables efficient mineral mapping and compositional analysis across diverse ore systems, including gold- and lithium-bearing environments.

Samples were scanned using an Elemission ECORE FLEX instrument equipped with a high-resolution line-scan camera and a 1064 nm laser source, allowing elemental imaging over tens of centimeters at sub-100 µm resolution. Raw spectra and imagery were processed using an in-house software package, laspectools, to extract elemental features, assemble multidimensional datasets, and classify minerals through machine-learning algorithms. Mineral maps generated from LIBS were validated against TIMA results, showing comparable accuracy but a dramatic improvement in speed (5 min vs 2.5 h at 30 µm resolution).

The workflow efficiently integrates spectral, imaging, and microanalytical data, enabling both rapid screening and quantitative assessment of mineralogy and chemistry. While the current workflow relies on conventional machine-learning algorithms, ongoing work at CSIRO aims to evolve laspectools into an AI-driven framework through integration of deep learning, multimodal data fusion, and adaptive model retraining. Applied to multiple ore types, this approach delineates mineral zoning and elementenrichment trends, reducing analytical turnaround from weeks to hours. These results highlight the potential of LIBS, when coupled with machine learning, as a versatile and industry-ready tool for geoscientific research and exploration.

Keywords: LIBS, ML, mineral mapping, ore systems

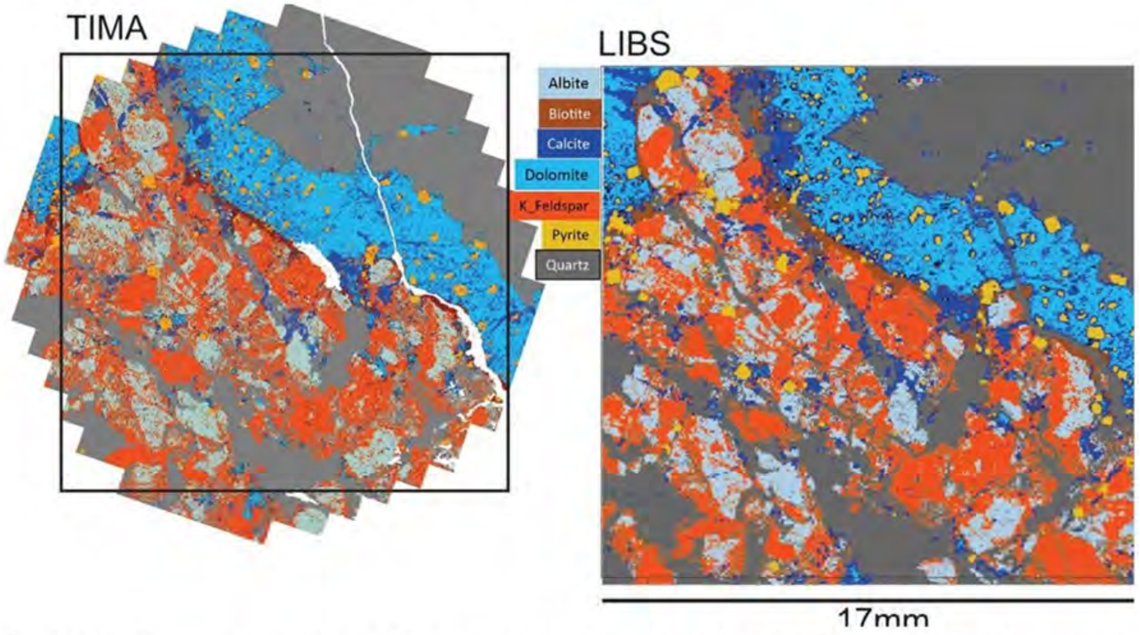

Fig. 1 Mineral maps generated from LIBS were validated against TIMA results, showing comparable accuracy but with a drastic reduction in acquisition time (5 min vs 2.5 h at 30 µm resolution).

O30

Downhole LIBS sensor: in-situ analysis of mining drill holes

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The global shift toward sustainable energy demands increased mineral resource discoveries which will require more efficient and environmentally responsible approaches to exploration and extraction. Understanding subsurface geology is central to these efforts, and drilling remains a key method for acquiring geological information.

Rapid acquisition of geochemical data from drill core and chip samples has become increasingly important for improving decision making and operational efficiency in mineral exploration, mining, and processing. Handheld tools and scanners equipped with X-ray fluorescence (XRF) or Laser-Induced Breakdown Spectroscopy (LIBS) sensors are effective for top-of-hole core or chip sample analysis, provided depth constraints are well defined. However, drill holes with poor sample recovery, composited rock chips, or uncertain depths will benefit more from in-situ chemical analysis. This approach can also reduce the number of samples sent for laboratory testing, lowering costs, minimising manual handling, and reducing waste. Existing wireline (downhole) logging tools based on sensors such as natural gamma, and Prompt Gamma Neutron Activation Analysis (PGNAA) provide valuable insights into physical rock properties and bulk chemistry; however, there are limitations in measuring geochemical composition for a broad suit of elements.

We present outcomes from a compact LIBS instrument designed for deployment downhole via winch and wireline, enabling both power delivery and real time data transmission. The 76 mm diameter instrument has a self-contained miniaturised 40 mJ nanosecond Nd:YAG pulsed laser, spectrometers, and active focusing mechanism to accommodate the irregular surfaces of drillhole walls. Our research, conducted through MinEx CRC in collaboration with partners from the mining industry, targets scenarios where drill core is not recovered. This includes percussion or auger drilling where the rock chips are collected and aggregated in 1-3 meter interval batches at the surface, which disrupts spatial relationships between lithologies and mineralogy. In its current configuration, the downhole LIBS sensor performs a line scan of the drill hole surface. The spectral or compositional data can then be composited at intervals tailored to specific applications.

Drill holes present challenging conditions; they have rough surfaces and surface moisture or are often flooded with groundwater or drilling fluids. While deep holes typically yield core samples, shallow percussion drilled holes suffer from reduced spatial resolution and are less likely to flood, making them ideal candidates for this technology. In these environments we have demonstrated a single-pulse LIBS sensor operated as a wireline instrument that can provide geologically meaningful data, whilst in parallel exploring double-pulse LIBS for more challenging conditions such as flooded drill holes.

Keywords: wireline logging; mining; downhole LIBS; geochemistry sensor.

O31

Nanostructured substrate produced by CO_2 laser photothermal treatment for emission signal enhancement

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Recently, CO_2 laser-assisted reduction of metallic nanoparticles has attracted great interest due to its simplicity, automation and versatility, as it does not require special controlled conditions or reagents to achieve precise thermal reduction [1]. The purpose of the present work is to fabricate nanostructured substrates via photothermal treatment using CO_2 laser, aiming at enhancing the emission signal of metallic ions (Ba^{2+}, Cu^{2+}, Mn^{2+}, Cr^{3+} and Al^{3+}) in solution by NELIBS. Initially, a 300-µL aliquot of metallic precursor was dropped onto the center of a filter paper disc (Ø: 2.5 cm, Whatman 40), which was then dried at 60 °C for 60 min. The dried substrate was placed under a CO_2 laser scanner (WS 6040E) to induce the photoreduction of the precursor into nanostructures. Afterward, a 600-µL aliquot of sample containing 1.0 mg L^{-1} Ba^{2+}, Cu^{2+}, Mn^{2+}, Cr^{3+} and Al^{3+} was dropped onto the substrate and dried. A Q-switched Nd:YAG laser (Quantel, Brilliant, 5 ns, 90 mJ, 20 Hz) operating at the fundamental wavelength (1064 nm) was employed. The parameters evaluated for in situ photoreduction were: type (Au^{3+}, Ag^{+}, Cu^{2+} or Zn^{2+}) and concentration (0.5 - 10 mmol L^{-1}) of the metallic precursor, laser power (7.6 - 8.6%), scanning speed (60 - 110 mm s^{-1}), resolution (0.050 - 0.175 mm) and scanning mode. The substrates produced by using different precursors are shown in Figure 1a, whose nanoparticles are structured in a ring pattern. The higher signal was obtained using Ag^{+} ions as the metallic precursor at a concentration of 8.0 mmol L^{-1}. Furthermore, laser power energy from 7.6 to 8.2% provided low emission signals, due to insufficient energy to promote reduction and nucleation, resulting in limited AgNPs formation. On the other hand, higher laser power (8.6%) impaired the physical integrity of the filter paper, also providing reduced signal enhancement. Optimal signal intensity was achieved at 8.4% laser power. A scanning speed of 80 mm s^{-1} resulted the best results, while higher speeds (100 mm s^{-1}) reduced the photon-precursor interaction time. Moreover, a 0.050 mm resolution combined with x-bidirectional scanning mode also provided greater signal enhancement. Using the photothermal treatment, the NELIBS emission signal was enhanced up to 14x compared to the emission signal obtained without AgNPs (Figure 1b). The UV-Vis and scanning electron microscopy analyses indicated efficient immobilization of AgNPs on the paper microfibers. These results demonstrate the effectiveness of nanostructured substrates fabricated via an automatized process for the sensitive detection of metal ions in liquid samples using NELIBS approach. (INCTNanoVida, CNPq #406079/2022-6)

Keywords: Nanoparticles; photoreduction; CO_2 laser, liquid sample.

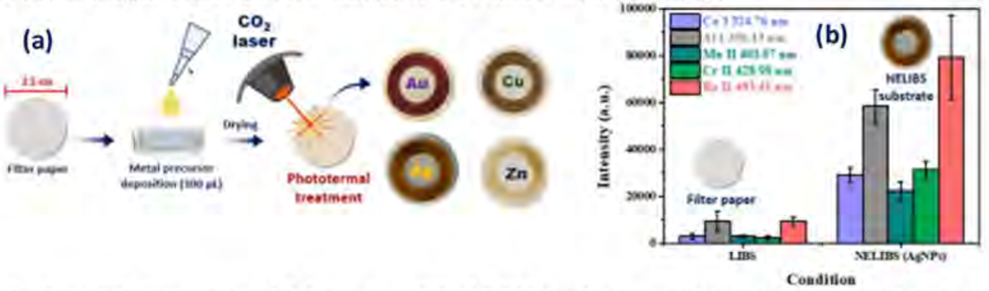

Fig. 1 (a) CO_2 laser-assisted fabrication of the NELIBS substrate and (b) emission signal intensity.

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I7

Exploring LIBS imaging at scale: how chemometrics changes what we can see

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Spectroscopic imaging is now more than ever at the heart of analytical chemistry. Thus, when we are particularly interested in the elemental distribution within complex and heterogeneous samples, we can say that µLIBS-imaging is today a highly effective technique and therefore highly valued. This is naturally explained by the many characteristics that are difficult to find simultaneously in other analytical techniques. We therefore have very simple sample preparation, analysis under ambient conditions, an excellent concentration dynamic range, excellent detection limits, a spatial resolution of around 10 microns, acquisition rates that can reach the kHz range, and a fairly straightforward implementation of multimodal measurements. On the basis of this observation, and given that the literature highlights the value of µLIBS imaging data through chemometric methods, one might assume that everything is fine. The purpose of this presentation is to show you that, despite these instrumental developments that have led to all these improvements, there are now two key points we need to focus on: increasing acquisition throughput and leveraging multimodality.

Our drive to go ever faster and analyze increasingly larger areas of interest in samples now compels us to use kHz lasers for this elemental imaging. Despite its potential, implementing such lasers in µLIBS-imaging would face diverse challenges mainly related to weak plasma emission and signal-to-noise ratio (SNR) degradation, particularly when applied to delicate biological samples. The first part of this presentation will then introduce methods to enhance SNR in fast µLIBS imaging, particularly for biomedical applications. We focus on denoising techniques suitable for high-frequency laser applications, comparing methods like Savitzky-Golay smoothing, Fast Fourier Transform, wavelet-based filtering, Whittaker Filtering, and Principal Component Analysis (PCA). Deep learning approaches will also be explored. These first results will demonstrate significant improvements in data quality, paving the way for more accurate and efficient elemental imaging in complex biomedical specimens using kHz lasers.

The second aspect we would like to develop in this presentation is the potential of multimodality in LIBS imaging. From our perspective, the future of analytical chemistry imaging lies in the development of multimodal approaches that combine molecular and elemental imaging, if we truly want to achieve an exhaustive exploration of complex samples. That is precisely where LIBS imaging has a role to play, in the sense that its instrumental implementation is relatively straightforward compared with other imaging techniques, owing to its fully optical nature. Of course, it's easy to say, but it's always harder to put into practice, especially since we also have to persuade colleagues from other imaging communities to invest time in these kinds of concepts. Our community has already begun developing multimodal approaches that combine different techniques (PIL, Raman, etc.), and we clearly need to keep pushing in that direction. Yet one modality is inherently part of any LIBS imaging setup and already built into the system: a standard visible camera. It produces data that, in practice, are almost always overlooked and seldom integrated with the elemental maps, even though they are directly complementary. As a consequence, we will demonstrate that data fusion between a visible image and the spectroscopic data cube can significantly enhance sample exploration. We will introduce aspects related to image registration as well as colorimetric space transformations. To illustrate our approach, we will focus on the characterization of an ancient mortar using LIBS imaging.

Keywords: µ-LIBS imaging, chemometrics, signal to noise ratio, denoising, multimodality, data fusion.

O32

Spatially Aware Refinement of LIBS Mineral Maps with Conditional Random Fields

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Laser-Induced Breakdown Spectroscopy (LIBS) enables rapid, in situ chemical imaging across diverse geological materials, yet routine use for ore characterisation is often constrained by data handling and quantification challenges. We address one practical bottleneck: pixel level classification that leaves unclassified patches and speckled boundaries that mask true geological texture. We present a spatially aware postprocessing workflow that promotes coherent lithological boundaries and geological contacts.

Starting from class probability maps generated by machine learning (ML) models, we fuse predictions by retaining the high probability minerals from the major stack and drawing the long tail directly from the minor stack to preserve rare species. To provide texture-preserving guidance, we project the full spectral cube into a CIE 1931 colour rendering at native spatial resolution, yielding an image that reflects LIBS-derived chemistry and fabric. A fully connected conditional random field then propagates confident seeds across space using a compact Gaussian smoothness term and a bilateral term guided by the LIBS RGB image. To respect mapped geology, we apply conservative edits only where legacy label areas fall below a user set threshold; elsewhere, original labels are retained. The refined mineral map improves visual interpretability for geologists by reducing unclassified regions and sharpening contacts while preserving minority phases.

Keywords: LIBS, Conditional Random Fields, Mineral Mapping, Machine Learning

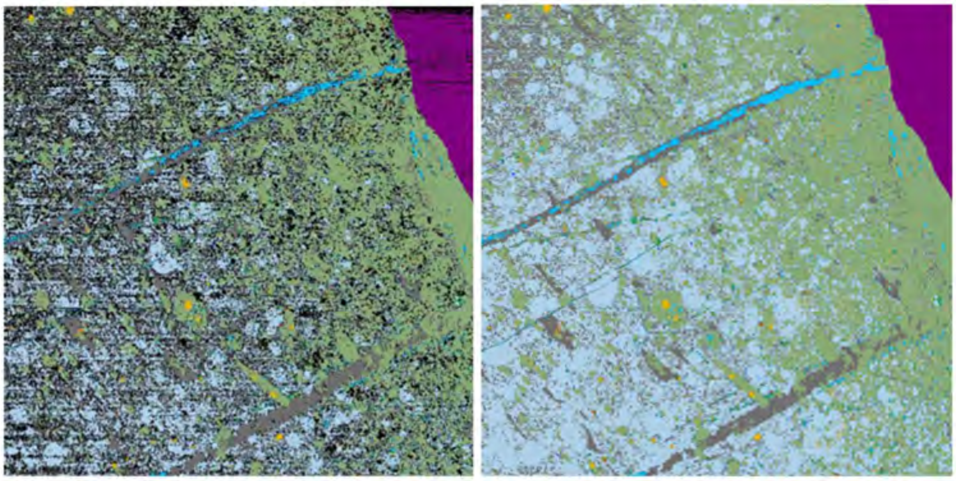

Fig. 1 Comparison of LIBS based mineral maps: the original machine learning prediction (left) and the map refined with a conditional random field (right)

O33

Investigating Depth Trends in ChemCam LIBS Data with Tensor Component Analysis

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The first extraterrestrial laser-induced breakdown spectroscopy (LIBS) instrument ChemCam, which belongs to the payload of NASAs Mars Science Laboratory (MSL) mission, has been measuring the geochemical composition of the Martian surface in Gale crater since landing in August 2012 [1,2] During the more than 4500 sols (Martian day) since the mission begin, a large amount of data was collected with more than 1 million single shot spectra from more than 4000 individual targets. Usually, a ChemCam measurement on one target follows a raster with multiple measurement points and at each point 30 laser shots are done resulting in 30 single shot spectra [3]. Those spectra enable an analysis with LIBS crater depth as each shot ablates material slightly deeper. The final crater depth depends on the rock but it usual in the range of 100 µm [3]. A correlation of elemental emission lines with depth can support mineral identification when assuming that the elements mainly belong to one mineral phase. Furthermore, the analysis of shot-to-shot trends can provide information about the dust coverage as dust is usually blown away by the LIBS plasma shockwave during the first shots. Also, thin coatings can be identified and analyzed with LIBS shot-to-shot data.

Here, we present the use of tensor component analysis (TCA) for a systematic study of potential depth trends in ChemCam shot-to-shot data. TCA can be understood as a generalization of two-dimensional decomposition methods (SVD, PCA, ICA, NMF etc) to more dimensions [4,5]. For ChemCam shot-to-shot data, the data is organized in a three-dimensional tensor with an observation dimension (measurement points), a depth dimension (the 30 shots) and a spectral dimension (Fig.1, left). TCA can be implemented in different ways and here we focus on parallel factor analysis (PARAFAC) [4,5] and use algorithms provided in the python *Tensorly* package [6]. With PARAFAC, the data tensor is represented low-rank model by a sum of rank-one tensors (Fig.1, right). We report on the application of TCA to artificially created data and to real ChemCam data from Mars. We investigate the best choice of number of ranks R and also the use of quantified abundances of major oxides (MOC) [7] per single-shot instead of the spectral data. The use of TCA to analyze depth trends in LIBS shot-to-shot data is relevant not only for ChemCam data, but also for data from other instruments, i.e. the SuperCam instrument on the Mars 2020 mission [8, 9].

Keywords: ChemCam; Mars; Decomposition; Depth Trends;

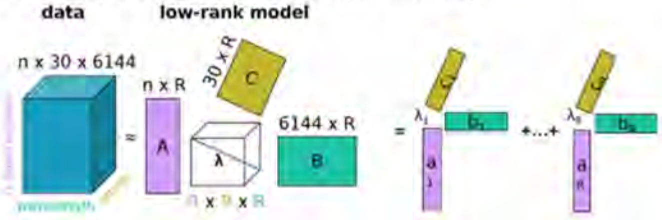

Fig. 1 Schematic representation how ChemCam shot-to-shot LIBS can be organized in a three-dimensional tensor and decomposed in R rank one tensors with PARAFAC.

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O34

Rapid Hardness Characterization of Steel via Femtosecond Laser-Induced Plasma Spectroscopy

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We investigated the potential of femtosecond laser-induced breakdown spectroscopy (fs-LIBS) for rapid and minimally invasive assessment of surface hardness in thermally treated steel samples. Conventional tactile hardness testing methods such as Brinell, Vickers, and Rockwell require extensive sample preparation and specific geometric conditions, making them less suitable for fast or in situ evaluations

Laser-induced breakdown spectroscopy (LIBS) provides a contactless method of material analysis with minimal surface damage and high spatial resolution. In previous work [1], we showed that nanosecond LIBS (ns-LIBS) leads to the formation of melt products and slag deposits around the ablation craters, which complicates subsequent surface hardness measurements and thus limits the spatial resolution. To overcome these limitations, we employed femtosecond laser pulses to generate reproducible plasmas on steel samples of varying hardness. By keeping LIBS-determining parameters such as laser pulse energy, surface roughness, and laser spot size constant, we analyzed the spectral variations in relation to the mechanical properties using an integrating spectrometer.

Our results reveal a correlation between the intensity ratios of iron emission lines and material hardness, highlighting the sensitivity of fs-LIBS to microstructural changes. Compared to ns-LIBS, fs-LIBS produces significantly smaller ablation craters, reducing surface alteration. Consequently, fs-LIBS represents a promising alternative for the rapid, minimally invasive hardness characterization of finely structured or heat-sensitive components.

Keywords: LIBS, steel; surface hardness; femtosecond laser

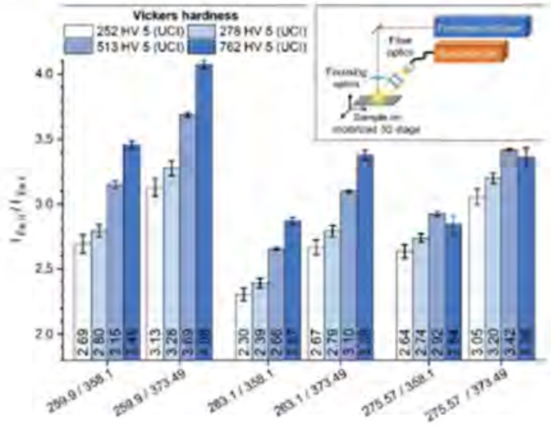

Fig. 1 Correlation between surface hardness and the ionic-to-atomic iron line intensity ratio in partially hardened 80CrV2 steel. Hardness was determined using the ultrasonic contact impedance method.

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O35

Application of molten-metal LIBS in the aluminum industry

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The history of chemical analysis of molten metal by laser-induced breakdown spectroscopy goes back nearly as far as the history of the laser itself [1]. Nevertheless, it took more than half a century for molten-metal LIBS to make significant penetration into primary and secondary aluminium production [2]. There, LIBS must compete in accuracy and repeatability with traditional sampling and analysis methods, usually employing spark optical emission spectroscopy [3] and/or X-ray fluorescence (XRF) [4].

A significant advantage that LIBS provides over the traditional analytical methods is the possibility to fully automate the sampling and analysis process by measuring the chemical composition of the molten metal directly. This allows sampling to be performed much more frequently while simultaneously improving plant safety, as the traditional methods still rely on human operators to manually extract molten metal for casting solid samples for analysis. Increasing the frequency of chemical analysis during aluminum melt processing is of great current importance as the fraction of recycled aluminum in the global aluminum production is growing steadily, requiring manufacturers to handle increased uncertainty in the chemical composition of their input streams.

Molten-metal LIBS analysis in an industrial environment is not without its challenges, especially on recycled material that can exhibit a large variability in chemical composition. Through extensive on-site trials carried out in recent years, however, the technology has been improved to achieve full technological readiness. The presentation will review these developments and provide an overview of the current state of industrial implementations of LIBS at different stages of the aluminum production process, including electrolysis, alloy production, and recycling.

Keywords: Molten-metal LIBS; Aluminum; Aluminum alloys; Industrial applications.

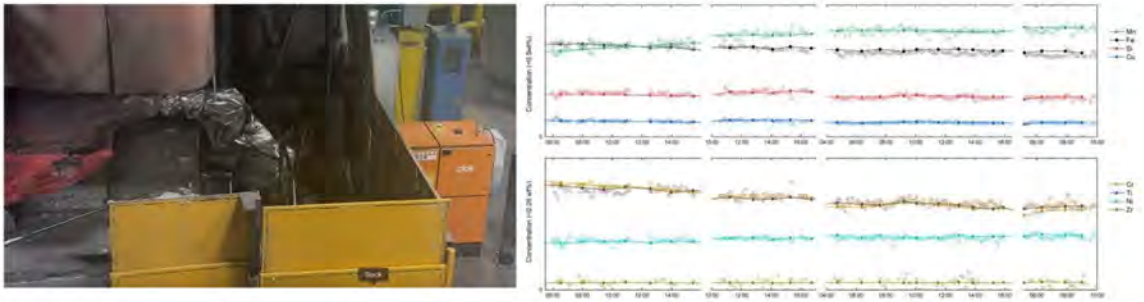

Fig. 1. Automated LIBS analysis of molten aluminum from a recycling furnace and comparison of LIBS results (open symbols) with lab analysis of cast samples (solid symbols).

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O36

Feasibility of Hydrogen Quantification in Metals by Laser-Induced Breakdown Spectroscopy (LIBS)

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Hydrogen quantification in metallic materials remains a long-standing analytical challenge due to its low atomic number, high mobility, and surface reactivity. Reliable micro-analysis of hydrogen would benefit numerous fields : from hydrogen embrittlement studies in steels and titanium alloys to hydride monitoring in nuclear zirconium claddings.

This work presents a preliminary demonstration of the feasibility of Laser-Induced Breakdown Spectroscopy (LIBS) for detecting and mapping hydrogen in metallic samples. A dedicated LIBS configuration was optimized for the H I 656.28 nm emission line under argon atmosphere, allowing spatially resolved measurements at the micrometric scale. Synthetic zirconium alloy standards with known hydrogen contents (10 – 4000 wppm) were used to establish a first quantitative calibration, showing a linear response and promising analytical performance.

The approach enabled the acquisition of hydrogen distribution maps within oxidized zirconium claddings (see Fig. 1) revealing local heterogeneities. These preliminary results were further compared with reference techniques in a recent PhD study [1] showing good consistency with Neutron Radiography Imaging (NRI) measurements (see Fig. 2) and paving the way for promising developments in the metallurgical industry.

Keywords: hydrogen analysis; distribution mapping; quantitative results; metallurgy; nuclear field

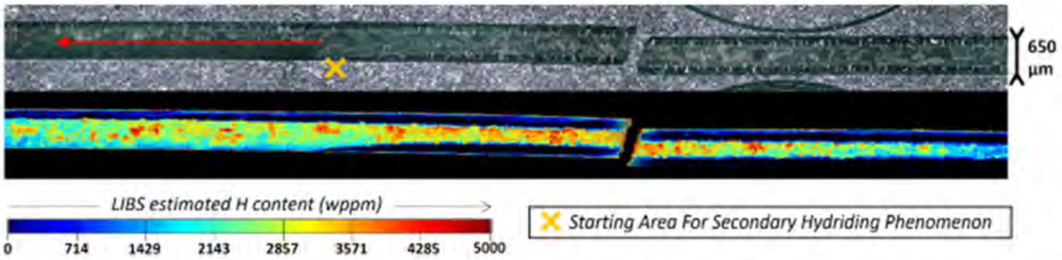

Fig. 1 Example of Hydrogen Mapping by LIBS on an Oxidized Cladding Strip (12 µm spatial resolution)

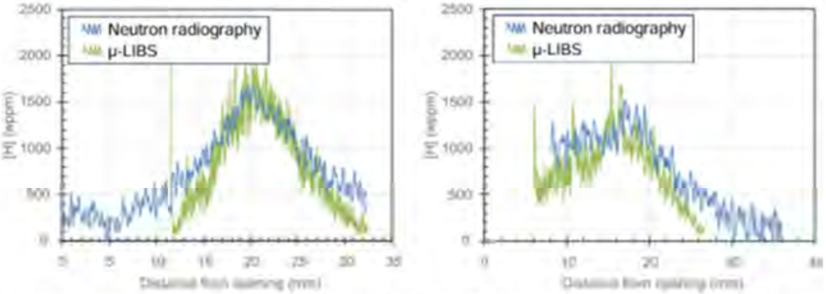

Fig. 2 Comparison between µ–LIBS average hydrogen content and NRI hydrogen axial profile

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I8

Innovative Advances in Laser-Induced Breakdown Spectroscopy: Enhancing Sensitivity, Precision, and Applications

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Laser-Induced Breakdown Spectroscopy (LIBS) has become a versatile analytical technique used across various scientific and industrial fields. Recent advancements in LIBS have significantly improved its sensitivity, precision, and applicability. We will examine recent developments, such as isotope analysis in LIBS plasmas [1], which opens new avenues for research in geochemistry and nuclear science. Additionally, we will highlight advances in traditional elemental analysis in terms of speed and reliability, making LIBS a preferred method for rapid material characterization [2]. Techniques for data reduction and analysis will also be explored, with a focus on innovative approaches to address challenges in LIBS analysis. We aim to provide an overview of the collaborative efforts required to achieve these technological advancements, emphasizing the contributions of leading research institutions and industry partners worldwide.

Keywords: LIBS; Particle analysis; Improved sensitivity; Isotopic analysis.

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O37

Depth-resolved picosecond LIBS of deuterium retention in displacement-damaged tungsten

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Nuclear fusion reactors require wall materials that both, can survive high heat and plasma particle loads without disrupting the plasma by increasing impurity concentrations above the threshold and retain as little of the hydrogen fuel as possible. A material that meets both requirements is tungsten and will thus be used to manufacture plasma-facing components (PFC) for ITER. However, during fusion operation, the PFC is bombarded by high-energy neutrons, which are used to couple out energy and to breed new fuel. They also damage the tungsten structure by introducing defects. An increased concentration of defects causes an elevated hydrogen retention as hydrogen isotopes can accumulate in the defects. Especially the hydrogen isotope tritium, which is needed for the Deuterium-Tritium (DT) fusion reaction, is critical from the safety perspective in PFCs when trapped. Due to safety regulations, ITER will only be allowed to have 700 g of mobilisable tritium in the reactor, the amount of which needs to be tracked. In-situ ready laser-based composition analysis techniques, such as laser-induced breakdown spectroscopy (LIBS), have a large potential for this application.

In addition to the safety matters, only tritium used in the fusion reaction contributes to the breeding of new fuel, and a large tritium reservoir in the PFC can lead to interruption of the fuel breeding cycle. The study of hydrogen retention in tungsten with neutron damage is therefore important for fusion research. Neutrons with the necessary energy spectrum for fusion-relevant damage can only be produced by fusion reactions or specific facilities, which are both not available for the time being. A way to study hydrogen retention in damaged tungsten regardless is by irradiating tungsten with 10.8 MeV W^{3+} ions from a particle accelerator. This inflicts displacement damage (here 0.23 dpa), thus inducing defects without transmutation of the material or introducing impurities. The samples were exposed to a deuterium plasma in the low-energy plasma device PlaQ and partially thermally outgassed afterward to produce samples with varying deuterium concentrations (0.01 to 1%) [1]. These were measured with Nuclear Reaction Analysis (NRA), which was used as a reference, and analysed with LIBS.

The depth-resolved LIBS measurements produce deuterium depth-profiles (15 nm depth-resolution) that show the transition from the deuterium-rich volume close to the surface to bulk tungsten in agreement with calculated damage profiles of the used ions. The transition depth is in agreement with NRA (depth resolution of 160 nm) results as well. A high deuterium peak close to the surface can be explained by varying ablation rates and thermal depletion in the depth by previous laser pulses. Simulations of thermal hydrogen movement and defect annealing in the material after ablation provide the basis for the latter.

The study shows the potential of LIBS for in-situ fuel retention measurements and provides the basis for first limit of detection estimates of fuel in PFCs.

Keywords: fusion; plasma-wall interaction; hydrogen isotopes; damaged tungsten

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O38

In-situ Residual Hydrogen Isotope Analysis by Laser Induced Breakdown Spectroscopy

Rongxing Yi[1], Arkadi Kreter[1], Gennady Sergienko[1], Erik Wuest[1], Miroslaw Zlobinski[1], Liang Gao[1], Christoph Kawan[1], Mauricio Gago[1], Huace Wu[1], Sebastijan Brezinsek[1,2]

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In future fusion device ITER and DEMO, residual hydrogen (H) isotope analysis is a critical safety issue related to tritium cycle. Accurate measurement of H isotopes at designed point throughout the whole plasma discharge process is therefore a significant requirement. Quadrupole mass spectrometer (QMS) is widely used for residual H analysis. However, two major limitations, high pressure environment and measurement of particles with the same mass, limit its application. Therefore, we introduce laser induced breakdown spectroscopy (LIBS) as an analytical tool for residual H isotope analysis, which can work under higher pressure and separate H isotope well.

We performed LIBS in a small vacuum chamber under a high vacuum environment (2×10-7 mbar) and in our PSI-2 linear plasma device at pressures ranging from 10-6 to 10-3 mbar, respectively. In the high vacuum environment, a linear H adsorption process was observed, which was found to be very sensitive to the pressure (higher pressure, faster adsorption). In PSI-2, a clear linear relationship between deuterium (D) partial pressure and its LIBS signal was recorded from 10-6 to 10-3 mbar. This work not only enables the direct observation of the adsorption process but also demonstrates the feasibility of using LIBS for the detection of residual H isotopes, achieving a relatively low detection limit at the 10^{-7} mbar level.

Keywords: Hydrogen, Fusion, Adsorption, Laser, Plasma

O39

Utilizing modern fiber lasers for LIBS

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The development of laser sources plays a very important role in the quick advancements in the field of LIBS. However, the development of fiber lasers went mostly unnoticed by the wider LIBS community. These laser sources, traditionally used in industrial cutting and welding processes, despite their high-power output (hundreds of watts) and are very robust nature, were neglected, because they used to work only in continuous mode. Modern fiber lasers however, offer pulsed output with a couple of mJ-s pulse energy, which can be adequate for certain tasks [1,2]. Furthermore, the pulse duration and the pulse repetition rate can be varied in a reasonably wide range, while their price is a fraction of the ones traditionally used in research.

In the recent years, our groups made experiences with modern fiber lasers to evaluate the feasibility of their usage in LIBS. The initial experiments proved that they are not just suitable for standard analytical tasks such as quantitative or qualitative analysis, but their unique set of features makes them capable for fundamental research, like no other laser sources currently on the market. The relatively low energy and elongated profile of the pulses are very efficient in ablation and in the generation of low temperature plasmas [3], which means the ionic lines are less numerous, while the emission is mostly free from the background emission typical for the early stages of the plasma lifetime. It can make spectrometer gating and signal integration much simpler and robust.

A thorough set of investigations of single pulse, double pulse and even continuous irradiation experiments was performed. The effects of various parameters, such as energy, duration and shape of the pulse as well as inter pulse delay were investigated on the generated signal focusing mainly the signal intensity, the self-absorption and the width of the peaks as well as the plasma properties.

Keywords: Fiber laser, fundamentals, application, DP-LIBS, MP-LIBS

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O40

Utilizing modern fiber lasers for LIBS

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A thorough set of investigations of single pulse, double pulse and even continuous irradiation experiments was performed. The effects of various parameters, such as energy, duration and shape of the pulse as well as inter pulse delay were investigated on the generated signal focusing mainly the signal intensity, the self-absorption and the width of the peaks as well as the plasma properties.

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O41

Femtosecond vs. Nanosecond Laser-Induced XUV Spectroscopy (LIXS)

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In contrast to laser-induced breakdown spectroscopy (LIBS), measuring after a delay as long as a few microseconds, laser-induced XUV spectroscopy (LIXS) takes advantage of emissions from the very first instant of the pristine plasma. This process exhibits stable and intense line and recombination emissions in the XUV-range. Therefore, common challenges for precise measurements (*e.g.* quantification efforts) in LIBS caused by signal intensity fluctuations due to matrix effects and plasma-flicker noise are improved, as shown for ns-pulses [1].

A femtosecond laser (pulse length ~100 fs) interacts fundamentally different with matter than a nanosecond laser. Of the many photons needed for ionization of the sample, less are absorbed *via* inverse *Bremsstrahlung* and more in a Franck-Condon multiphoton absorption (MPA) process. In combination with the higher peak power, and therefore higher initial plasma temperature (> 10 eV), atoms are selectively ionized to a higher degree while at the same time thermal dissipation and equilibration is reduced. This specificity in excitation leads to a reduced background and the highly ionized atoms overwhelmingly emit the desired XUV-radiation. Thus, fs-LIXS promises to lead to "cleaner" spectra with sharper separation of the emission lines.

The capabilities of a fs-LIXS setup in comparison to ns-LIXS will be discussed. Samples of pure elements (Al, Si, Ni, Fe, Mg), as well as composite samples (CaF, LiF, PTFE, polypropylene) serve as model systems to demonstrate these capabilities.

Keywords: LIXS; femtosecond; XUV; elemental analysis.

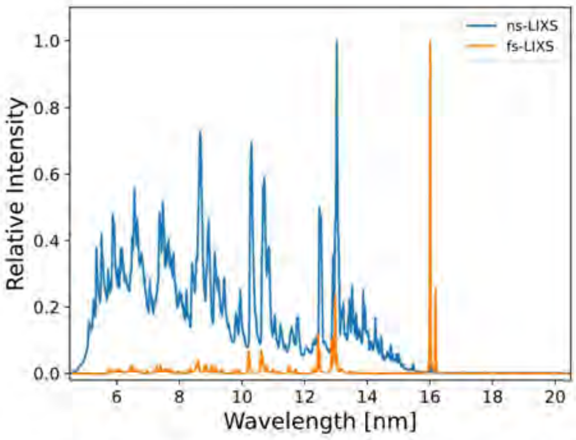

Fig. 1 ns-LIXS (1064 nm, 10 ns, 600 mJ, single pulse) spectrum in blue and fs-LIXS (800 nm, 100 fs, 700 μJ, 100 pulses) spectrum in orange of pure aluminum.

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DAY 4

THURSDAY | 29TH JANUARY

09:00 | SESSION 11: FUNDAMENTAL *CHAIRS: JÖRG HERMANN / LUKAS RETTERATH*

- **09:00** | **KEYNOTE 4: Mohamad Sabsabi** *Expanding Horizons of LIBS for On-Line and In-Situ Analysis*
- **09:30** | **INVITED 9: Christoph Gerhard** *Modelling contributions to understanding physics of LIBS*
- **10:15** | **Sponsor 5: Photonics Industries (Hans Taylor)** *New Options for DPSS LIBS Laser Sources*

10:45 | TRIBUTE VINCENT DETALLE : ALEXANDRE SEMEROK

11:15 | *LUNCH*

12:30 | BUS TO PARIS

14:30 | CITY TOUR / FREE TIME

20:30 | GALA DINNER

K4

Expanding Horizons of LIBS for On-Line and In-Situ Analysis: Opportunities and Challenges

Mohamad Sabsabi, Paul Bouchard, Aissa Harhira, Josette El Haddad, André Beauchesne, Francis Vanier, Elton Soares Filho De Lima, Christian Padioleau, Francis Boismenu, Antoine Hamel, Daniel Gagnon

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Laser-Induced Breakdown Spectroscopy (LIBS) has emerged as a powerful atomic emission technique that enables rapid, in-situ elemental analysis of solid, liquid, and gaseous materials. By focusing a high-energy laser pulse onto a sample surface, a microplasma is generated, and the resulting emission spectrum reveals the elemental composition. The simplicity of the LIBS principle contrasts with the complexity of the underlying physical processes, which continue to be an active area of research.

In recent years, LIBS has experienced remarkable growth, driven by the increasing demand for fast, versatile, and portable analytical tools across industrial, environmental, and research sectors. In the last five years, over 5000 publications and more than 40 commercial suppliers, in addition to more than ten handheld system manufacturers, reflect LIBS's rapid growth and technological maturity.

In our laboratory, extensive efforts have been dedicated to advancing LIBS performance and expanding its applications. Our work encompasses both fundamental and applied studies, with a focus on enhancing sensitivity and selectivity through techniques such as double-pulse excitation, laser-induced fluorescence coupling, resonance-enhanced approaches, and integration with complementary analytical techniques to meet industrial requirements. We will present recent developments in robust LIBS instrumentation designed for at line or on-line and field-deployable measurements.

This lecture will highlight NRC's contributions to LIBS technology, discuss its advantages and limitations compared to conventional analytical methods, and explore its role as a key enabling technology for metallurgy, aerospace, energy and mining applications. We will conclude with a perspective on emerging trends and future directions shaping the evolution of LIBS.

Keywords: In-situ measurements, LIBS instrumentation, hyphenated techniques, portable LIBS, resonance enhancement, mining applications

I9

Quantifying manufacturing-induced near-surface deviations in chemical composition of glasses via calibration-free LIBS

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Keywords: glasses, near-surface effects, calibration-free LIBS, depth-resolved LIBS

Even though glass is one of the most traditional workpiece materials, it has still an unbowed relevance for modern innovations and products in both cutting-edge technologies and everyday objects. Due to the large variety in glass types and applications, different methods for shaping and surface treatment are in hand. In most cases, the glass surface is in direct contact with different operating materials, leading to several exchange mechanisms such as interdiffusion, leaching of glass components, and implantation of foreign matter and thus a modification of the outermost glass surface with respect to its bulk material.

In this contribution, we report on the detection and quantification of such modifications using calibration-free LIBS on two multi-component glass types, processed by two fundamentally different methods. First, optical glasses manufactured via classical polishing applying ceria-based polishing suspensions were investigated. Second, solar cell cover glass produced via the float glass process, where the glass melt is poured on a liquid metal bath for surface smoothing, was considered. During LIBS measurements, several single pulses were applied successively at the same site, allowing depth-resolved analysis of the chemical composition. The evaluation of the obtained spectra was carried out via sensitivity-improved calibration-free LIBS as introduced in detail in [1].

Such analysis revealed that classical polishing induces a contamination of glass surfaces by traces from the used operating materials [2]. Moreover, leaching of glass network formers such as silicon was ascertained up to a depth of several microns. Hence, this investigation indicates polishing-induced interdiffusion at the outermost glass surface in the course of manufacturing. Such interdiffusion was also observed in case of solar cell cover glasses. Here, foreign matter from the liquid metal bath, namely tin, lead, and silver, was detected within the glass boundary layer close to the surface [3]. Also, a gradient-like depletion in glass constituents as for example magnesium and sodium towards the surface was observed, visualising exchange mechanisms between the liquid metal bath and the glass material.

The reliability of the data obtained via calibration-free LIBS was verified with the aid of ICP-OES and XPS measurements. The presented results thus demonstrate the suitability of the applied approach for the quantification of manufacturing-induced deviations in chemical composition of glass surfaces.

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O42

Spatio-Temporal Dynamics of Transient Boron Molecular Species in Laser Induced Plasma

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Laser-induced plasma (LIP) is a powerful technique for probing atomic, ionic, and molecula species, offering valuable insights for material and isotopic analysis [1]. When a high-intensity lase interacts with a target, it generates a plasma plume exhibiting non-uniform species distributions that emi characteristic signatures. These emissions evolve in space and time, influenced by plasma temperatur gradients, recombination, dissociation, and fragmentation processes within the plasma [2] Understanding these dynamics is essential for identifying formation pathways of transient molecules an improving analytical applications. This work focuses on the spatio-temporal behaviour of boron-base molecular emissions, particularly the (0-2) BO:B-X and (200-000) BO_2:A-X ro-vibrational transitions

The results revealed distinct spatial and temporal emission trends. BO spectral intensit increased from the ablation site to the middle plasma region before decaying, while BO_2 emission peaked at the outer plasma regions. Temporal evolution showed BO_2 intensity maxima initially appeare far from the surface and shifted closer with time, indicating dynamic redistribution within the plasma Importantly, the spatial distribution of both species ruled out direct ejection from the sample surface instead highlighting plasma-mediated formation mechanisms. LIP imaging confirmed thes observations, correlating emission signatures with plasma regions. Temperature profiling using th Boltzmann plot method demonstrated that BO forms in higher-temperature zones, particularly in th plasma core, while BO_2 is favoured in cooler regions at the plasma periphery (Fig. 1). Additiona experiments varying ablation wavelength and ambient atmosphere reinforced that BO dominates i hotter regions, whereas BO_2 forms preferentially in low-temperature zones. This comprehensiv investigation advances the understanding of boron molecular dynamics in LIP. By identifying optima spatial and temporal observation windows, detection sensitivity and selectivity for spectrochemica analysis can be significantly enhanced.

Keywords: Molecular emission; Laser induced plasma; Boron; Plasma temperature.

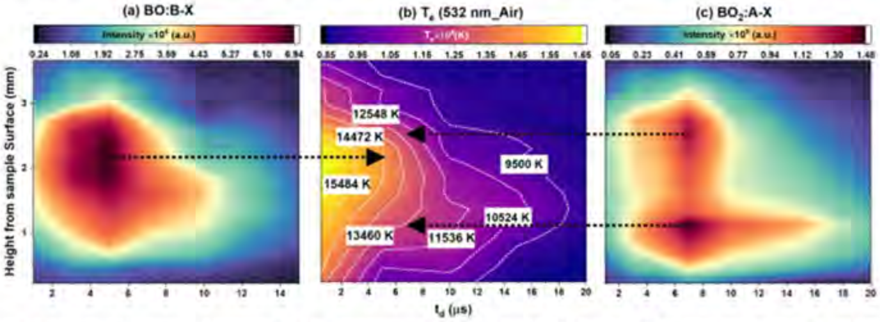

Fig. 1 Correlation of spatio-temporal temperature profile with BO and BO_2 molecular emission profiles

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In Memory of Vincent Detalle (1969 - 2025)

It is with deep sadness that we announce the sudden passing of Vincent Detalle, a professor at CY Cergy Paris University specializing in experimental sciences and engineering for cultural heritage, on Tuesday 4 March 2025.

Since joining the Historical Monuments Research Laboratory (LRMH) in 2004, where he led the mural paintings division for 12 years, and later at the Center for Research and Restoration of the Museums of France (C2RMF) until 2022, Vincent pioneered numerous research and development initiatives in heritage science. His doctoral work focused on Laser-Induced Breakdown Spectroscopy (LIBS), leading to various laser applications in material characterization and conservation-restoration, such as laser cleaning of easel paintings and the reconversion of blackened minium in murals.

Aware of environmental impacts on cultural heritage preservation and committed to effective, non-invasive restoration methods, he collaborated with academic partners both in France and internationally on innovative projects. These included monitoring artworks in situ using methodologies like holography, stimulated infrared thermography, and optical coherence tomography for varnish thinning control. Vincent actively participated in European research collaborations like CHARISMA and the IPERION projects, particularly on in situ analyses (MOLAB), and was instrumental in establishing the sustainable E-RIHS infrastructure and its French national node.

Since 2011, he had been involved with the French LabEx Patrima, EquipEx PatrimEx, and the *Fondation des Sciences du Patrimoine*. He initiated numerous projects supported by the Foundation, notably the EquipEx+ ESPADON, where he served as scientific coordinator. This project combines instrumental development and digital structuring around the concept of the "augmented heritage object". He was also actively involved in the setting up the European Cultural Heritage Cloud.

Vincent was passionate about mentoring young researchers and collaborating with scientific partners, always eager to explore new frontiers. He believed that heritage science should be rooted in cutting-edge research on material behaviour, continually challenging and expanding existing boundaries. His inspiration and influence are profoundly missed.

The C2RMF and LRMH join us in extending our heartfelt condolences to his family and loved ones.

DAY 5

FRIDAY | 30TH JANUARY

09:30 | SESSION 12: MULTIMODAL & INSTRUMENTATION

CHAIRS: CHRISTOPH GERHARD / FLORIAN MOURLIN

- **09:30 | INVITED 10: Pavel Pořízka** *Beyond LIBS, merging modalities to gain more comprehensive information*
- **10:00 | Oral 43 - Maxime Legallais** *Ultimate detection of lithium by LIBS in LiF atomic layers*
- **10:15 | Oral 44 - Gyula Kajner** *Nanoporous glass: A versatile substrate for calibration and liquid sample analysis*
- **10:30 | Oral 45 - Laura García-Gómez** *Improved Detection Capabilities of Molecular Emission in Microwave-Assisted Laser-Induced Plasma*

10:45 | COFFEE BREAK

11:15 | SESSION 13: INSTRUMENTATION 3 *CHAIRS: CÉCILE FABRE / GEORGE COOK*

- **11:15 | INVITED 11: Cristina Méndez-López** *Determination of total fluorine in organic liquid matrices: on the road to gasoline screenings*
- **11:45 | Oral 46 - David Douglas** *Integrating LIBS and LA-ICP-MS for High-Resolution Fluorine Mapping*
- **12:00 | Oral 47 - Aïssa Harhira** *Innovative Real-time LIBS Applications for Efficient Midstream Mineral Processing*
- **12:15 | Oral 48 - Marcos López Ochoa** *LIBS imaging for the identification of microplastics in the environment*
- **12:30 | Oral 49 - Mehdi Maghsoudi Sarteshnizi** *Quantification and Oxidation Tracking of Lithium in Liquid Aluminum Alloys*

12:45 | *LUNCH*

14:00 | CLOSING CEREMONY

I10

Beyond LIBS, merging modalities to gain more comprehensive information

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Tomáš Zikmund[1], Marcela Buchtová[2], and Jozef Kaiser[1]

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In materials and life sciences, correlative microscopy is a powerful approach that integrates data from multiple imaging techniques to provide a comprehensive view of a sample's chemical and structural properties. This talk will explore our efforts to push beyond the boundaries of traditional LIBS (LaserInduced Breakdown Spectroscopy) elemental imaging by correlating it with a suite of complementary modalities. We will detail our methodology for combining LIBS with elemental mapping techniques to gain complementary and reference analysis; Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS), X-Ray Fluorescence (XRF), and Scanning Electron Microscopy Energy Dispersive X-Rays (SEM-EDX). Moreover, molecular and structural imaging from Raman spectroscopy and X-Ray Computed Tomography (XCT) will also be introduced to provide more complex information about investigated samples. A significant challenge in this multi-modal approach is the variability in sample preparation and the subsequent need for precise image registration, particularly given the diverse performance metrics and resolutions of different instruments. [1] We will discuss our solutions for aligning and merging these disparate datasets. We will briefly present several case studies and namely forcus on multi-modal analysis of human tooth ankylosis [2] that demonstrate how this integrated approach overcomes the limitations of single-technique analysis to provide a more complete understanding of complex materials.

Acknowledgements
The authors gratefully acknowledge the support of Czech Science Foundation (GACR 25-16166S and 25-18588L).

Keywords: LIBS; LA-ICP-MS, multimodal analysis, image registration, image segmentation

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O43

Ultimate detection of lithium by LIBS in LiF atomic layers

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Gunay Yildirim[1], Bruno Bousquet[4], Maxime Legallais[1]*

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The growing number of industrial applications requiring thin-film materials is prompting the development of new characterization methods. In this context, this work aimed to assess the sensitivity of LIBS with regard to the analysis films with ultimate thicknesses prepared by atomic layer deposition (ALD). This deposition method, based on a combination of self-limiting surface adsorption mechanisms and sequential exposure to reactants, allows an excellent control of film thickness at the angström scale and beyond. LiF films, which are commonly used in photovoltaic cells, were prepared by injecting sequentially Li- and F-containing precursors in the reaction chamber and used as a case study. By using laser-induced breakdown spectroscopy imaging, we confirm the very good spatial homogeneity of LiF films deposited on silicon wafers. Using samples prepared with descending numbers of ALD cycles, we demonstrate that lithium can be detected in a film obtained after only one ALD cycle. From that, a limit of detection (LOD) of approximately 0.27-0.93 fg/ng (i.e. 270-930 ppb) was achieved for the Li I line at 670.8 nm and for single-shot LIBS analysis. Given the 100 Hz repetition rate of the laser shots, LOD decreases by a factor of 10 in one second driving to 0.019-0.065 fg/√Hz. Such level of detection limit paves the way for future utilization of LIBS for the chemical characterization of thin films.

Keywords: Lithium Fluoride; Atomic Layer Deposition; Laser Induced Breakdown Spectroscopy; Limi of detection

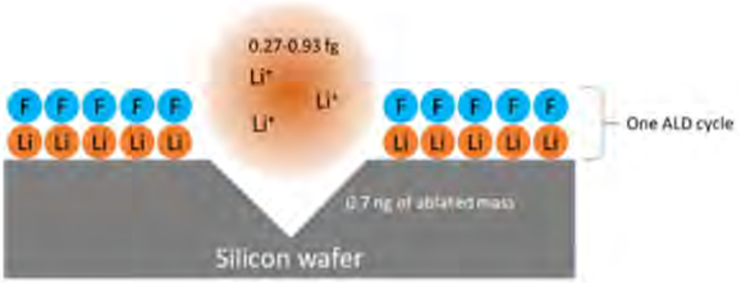

Fig. 1 Schematic representation of one ALD cycle of LiF after LIBS ablation. LOD for the Li I line at 670.8 nm is indicated as well as ablated mass of Si.

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O44

Nanoporous glass: A versatile substrate for calibration and liquid sample analysis in LIBS

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Over the past two decades LIBS has emerged as a prominent and powerful tool in atomic spectroscopy, however, the technique still faces persistent challenges and limitations on multiple fronts that remain to be overcome. Among these, a key limitation is the scarcity of reliable and accessible matrix-matched calibration standards for samples with complex composition (e.g. unknown geological or biological samples) which are essential for quantitative analysis. Another enduring challenge in LIBS is the efficient and accurate analysis of aqueous solutions. This is the result of multiple physical phenomena (e.g. splashing, plasma quenching), hindering reliable laser coupling and light collection as well as the formation of high emission plasmas [1].

Nanoporous glass (NPG) is a versatile material with unique characteristics, potentially suited for the production of custom solid-phase calibration standards as well as to serve as a substrate for the analysis of aqueous samples. When a NPG comes into contact with any aqueous solution, it gradually absorbs the liquid due to strong capillary action, while at the same time it absorbs the solute on its internal surfaces. Thanks to the high porosity (30%) and large specific surface area (250 m^2/g) of the NPG, the combination of these processes creates a concentrated and laterally homogeneous analyte distribution near the surface of the NPG through which the liquid sample was introduced. Once the glass is dried, a solid target is created with a composition characteristic of the liquid sample used. In practice this can be exploited to produce solid-phase calibration standards with an arbitrary composition by using solution standards or to convert aqueous samples into solid ones without compromising homogeneity. In our presentation, the analytical capability of this approach is showcased in detail, highlighting its strengths and weaknesses in quantitative trace analysis of liquids using LIBS [2].

Keywords: Nanoporous; Calibration; Liquid analysis; Microanalysis

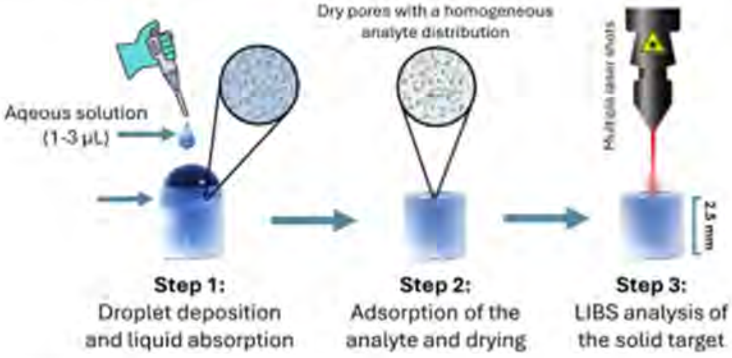

Fig. 1 An illustration of the use of the nanoporous glass substrate.

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O45

Improved Detection Capabilities of Molecular Emission in Microwave-Assisted Laser-Induced Plasma

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The detection of molecular emissions in LIBS remains a subject of active research, driven by the need to improve both signal-to-noise ratios and spectral definition. Different enhancement approaches have been proposed, including confinement of the plasma and re-excitation methods. Some of the most explored strategies have been double-pulse configurations (DP-LIBS) or multiple-pulse LIBS (MP-LIBS) [1]. While effective, these procedures often introduce considerable experimental complexity. In light of this, the current study explores microwave re-excitation (MW-LIBS), as a more accessible alternative capable of modifying plasma dynamics without additional optical alignment or laser devices. The introduction of microwave energy increases collisional activity within the plasma, extending its duration to the millisecond range and amplifying emission signals [2]. Molecular species were monitored under this regime, focusing on established emitters such as CaO and CN, as well as less commonly reported systems like SnO, which has not been previously described in LIBS literature. This research suggests that the most significant enhancements were observed under conditions approaching the plasma ablation threshold. Moreover, MW-LIBS enabled the observation of molecular emissions in the red and near-infrared regions, which are generally limited in conventional LIBS due to detector inefficiencies and reduced plasma radiative output. These findings provide new insights into the mechanisms of molecular formation in sustained plasmas and demonstrate the potential of MW-LIBS for enhancing molecular diagnostics.

Keywords: MW-LIBS, Re-Excitation, Molecular Emission.

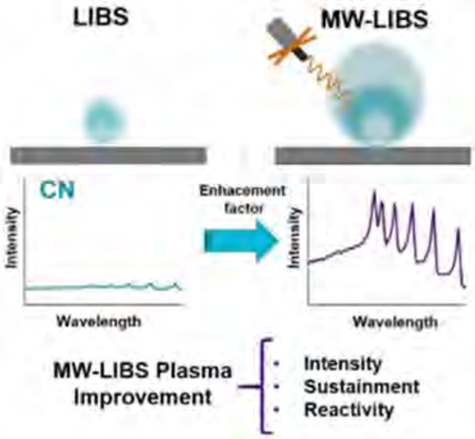

Fig. 1. Schematic illustration of the effect of microwave re-excitation (MW-LIBS) on plasma.

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I11

Determination of total fluorine in organic liquid matrices: on the road to gasoline screenings

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Liquid samples remain a secondary object of study in LIBS literature since, although the technique is suitable for the analysis of any kind of samples, liquids require the development of specific approaches (sampling strategies, instrumental modifications) in order to provide adequate levels of stability and reproducibility. In this work, the problematics of liquid sample analysis are addressed in conjunction with the challenge of halogen determination. A common approach to the latter, which is utilized here, is their indirect detection by means of halide molecule emission from molecules that are formed through recombination, in the laser-induced plasma, of the halogen and an alkali-earth metal.

Previous works [1,2] demonstrated the feasibility of halogen determination (F, Cl) in aqueous liquid matrices by nebulizing the sample on a Ca-containing target (calcium carbonate pellets and drawing paper), with limits of detection in the order of ppm and successful results when addressing inorganic halogens in real samples. Current research focuses on the determination of total halogen content when present as part of organic molecules instead of inorganic salts. Said detection was already demonstrated in [2] for an aqueous solution of a fluorosurfactant, but switching to organic liquid matrices was also needed at this stage in order to extend the methodology to the case of gasoline analysis. In this sense, Kowalewska et al. [3] demonstrated the significant dependence of the specific analyte utilized as fluorine standard (e.g. 1-fluoronaphtalene, 2,2,3,3,4,4,5,5-octafluoro-1-pentanol) when working with high-resolution continuum source molecular absorption spectrometry (HR-CS MAS).

An analogous study is done here, where two organic fluorine standards as well as two organic matrices are compared in order to gain insight into the generalizability of the methodology. Both standard calibration curves and standard additions procedures are carried out to study sensitivity of the methodology and to determine fluorine content in real gasoline samples, respectively.

Keywords: halogens; nebulization; liquid; gasoline

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O46

Integrating LIBS and LA-ICP-MS for High-Resolution Fluorine Mapping in Geological and Biological Matrices

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Quantifying fluorine in solid samples remains analytically demanding due to its high ionisation potential (17.42 eV) and poor plasma ion yield. Therefore, new analytical strategies capable of sensitive and spatially resolved fluorine detection are required. Here, we present for the first time a combined Laser-Induced Breakdown Spectroscopy (LIBS) and Laser Ablation-ICP-MS (LA-ICP-MS) approach for the simultaneous spatially resolved fluorine analysis in geological and biological matrices.

The method builds on the BaF^+ reaction method recently established for LA-ICP-MS [1], enabling indirect fluorine quantification via BaF^+ detection, while LIBS provides ionic fluorine (F 685.6 nm) and molecular fluorine bands (CaF 603 nm) in addition to complementary information on co-localized elements [2]. Geological standards, minerals, and biological tissues were analysed to evaluate sensitivity, precision, and matrix effects. LIBS data enhanced the interpretability of the BaF^+ maps, allowing discrimination between inorganic fluoride phases and fluorine bound in complex matrices. The results demonstrate that the LIBS–LA-ICP-MS coupling significantly improves confidence in fluorine detection and spatial correlation, offering a versatile platform for studying fluorine behaviour in natural and biological systems.

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O47

Innovative Real-time LIBS Applications for Efficient Midstream Mineral Processing

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The midstream critical mineral value chain is facing numerous challenges, including the need for reducing energy consumption, optimizing complex processing operations and minimizing the environmental footprint. Processing and refining are becoming more complex due to the variability in feedstocks from primary or secondary sources, as well as the presence of impurities and/or hazardous materials. Laser-Induced Breakdown Spectroscopy (LIBS) analyzers offer a promising practical solution as a rapid, non-contact and in situ analytical technique. The real-time data provided by LIBS enable fas process adjustment, improved efficiency, and support informed decision-making.

In this presentation, we will highlight potential midstream applications of LIBS developed at the National Research Council of Canada. Examples will be presented demonstrating its use for real-time mineral characterization on conveyor belts, monitoring of alkali metals in bulk aqueous solutions and in-situ analysis of molten metals.

Keywords: in-situ measurements; ore sorting; hydrometallurgy; pyrometallurgy

Fig. 1 (left) NRC testing platform for molten metal applications; **(right)** Real-time mineral characterization on a conveyor pilot line at NRC

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O48

Methodological approach based on LIBS imaging for the identification of microplastics in the environment. A case study for environmental samples

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This work reports the detection and identification of microplastics (MPs) by constructing LIBS images from the emission lines of different markers, In recent years, interest regarding the detection of MPs has risen exponentially. Current techniques carry severe drawbacks such as high analysis time and equipment costs or the need of a complicated sample treatment. For this reason, the present work proposes a protocol for studying MPs that involves a novel, simple, and rapid sample preparation method, combined with a single LIBS image scan, which enables the construction of the particle distribution in the filter for the detection and classification of MPs.

Firstly, four types of plastics, were crushed and suspended in water in order to emulate a real sample. As the preparation step, MPs suspended in water were isolated using a laboratory filter. Then, in order to prepare them for LIBS analysis, they were immobilized in doublesided adhesive tape in a microscope glass that acted as a physical support. An evaluation of the MPs fingerprint allowed for the detection of individual markers associated with each MP type.

Combining spectrum normalization and isolation of the wavelength corresponding to the emission of each marker allowed for the obtention of LIBS images corresponding to the distribution maps of the different MPs. This way, a selective differentiation of MPs in a mixture sample could be achieved in a way that could help bring a better understanding of MPs pollution in real and more complex samples. Not only that, but the simplicity of this working protocol makes it an interesting candidate to apply at a bigger scale in order to detect and classify different kinds of MPs in environmental samples.

Keywords:.

LIBS Imaging, Microplastics detection, Emergent pollutants, Environmental samples

O49

Quantification and Oxidation Tracking of Lithium in Liquid Aluminum Alloys via Laser-Induced Breakdown Spectroscopy

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Kristjan Leosson[2,*]

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Laser-Induced Breakdown Spectroscopy (LIBS) has proven effective for quantitative analysis of trace elements in molten aluminum alloys; however, challenges arise when detecting highly reactive and volatile alloying elements such as alkali and alkaline earth metals at elevated temperatures [1]. Among these, lithium (Li) presents a particular difficulty due to its low number of prominent transitions and strong self-absorption, which make accurate detection challenging. The pronounced reactivity of lithium with oxygen and refractory materials leads to oxidation and evaporation losses during measurement, promoting the formation of oxide phases on the melt surface that alter the local composition and influence the LIBS emission signal. For the same reason, tracking Li in aluminum production, especially recycling, is important due to its potentially detrimental effects.

In this study, LIBS was employed for in situ analysis of Li in molten Al–Li alloys, focusing on both its quantification and oxidation behavior. Time-resolved measurements revealed progressive Li loss through oxidation and evaporation during the melting and holding stages. Interactions with other alloying elements in the melt were also studied. The results demonstrate that optimized LIBS conditions enable reliable Li quantification and effective tracking of its oxidation dynamics in molten aluminum, confirming LIBS as a promising tool for real-time process monitoring in alloy production.

Keywords: Molten-metal LIBS; In situ analysis; Lithium quantification; Oxidation behavior.

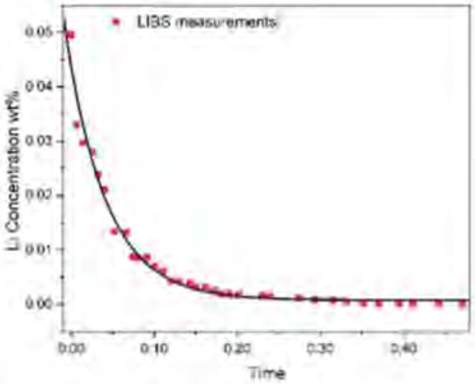

Fig. 1 Temporal evolution of lithium concentration in aluminum melt measured by LIBS, showing a decay (1/e) time of 4.9 minutes.

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POSTERS

P1 Alexandre Semerok *Analytical Model of Crater Formation at Laser Ablation*

P2 Sanath Shetty *Composition and depth analysis of transition metal boride using vacuum UV LIBS*

P3 Alexandre Cherrier *Effect of the electron density and plasma temperature on the plasma emissivity: a pathway to LIBS signal enhancement*

P4 Yiqin Wang *Efficiency evaluation of fuel retention diagnostic in first wall by LID-QMS: Based on LIBS*

P5 Christoph Egerland *Fitting LIBS plasma using gradient descent*

P6 Paul Andrieu *Influence of experimental conditions on LIBS measurement sensitivity*

P7 Anandhu Mohan *Isotopic Fractionation in Laser Induced Plasma (LIP) Plumes*

P8 Jean-Baptiste Sirven *Quantification of matrix effects observed in LIBS analysis of metal alloys*

P9 Pavel Veis *Elemental analysis of liquids using LIBS acoustic levitation in different stages of CW laser drying*

P10 Nan Zhao *Wavelength Drift Correction Method for Laser-Induced Breakdown Spectroscopy Based on Phase Correlation*

P11 Sid Ahmed Beldjilali *Calibration-free LIBS analysis of Diatomite for High Purity Silicon Extraction*

P12 Olivier Musset *Can LIBS explain the color of a sample?*

P13 Luisa Lemerle *Multielemental quantification by CF-LIBS assisted by a deep learning model trained on simulated spectra*

P14 Anton Radomtseu *Multiparametric processing of LIBS spectra of low-alloy steels*

P15 Clara Burgos Palop *Unveiling mineral phase distribution in the Chelyabinsk LL chondrite using LIBS mapping and cluster analysis*

P16 Olivier Musset *Use of Rank Transformation to Correct Flatness Defects in High-Resolution LIBS Imaging*

P17 Olivier Musset *A Python application for processing LIBS spectra*

P18 Marketa Stranikova *Advancements in Polymer Type Determination in the Plastic Industry using Sci-Trace/M-Trace LIBS Technology*

P19 Yuge Liu *Cross-Instrument Data Utilization Based on Laser-Induced Breakdown Spectroscopy (LIBS) for The Identification of Akebia Species*

P20 Claudio Sandoval-Muñoz *Determination of sulfides by HSI coupled with μ-LIBS and their use as a pathfinder to gold mineralization*

P21 Rania Guendouz *Effect of Particle Size on LIBS Emission and Structural Characteristics of Iron-Based Soils*

P22 Jordan Fernandes *Accurate Laser Spot Characterization for Enhanced Micro-LIBS Imaging via Knife-Edge Profiling*

P23 Samy Guellour *High-Resolution Laser-Induced Breakdown Spectroscopy for Micron-Scale Geomaterial*

P24 Luisa M. Cabalin *High-Resolution Laser-Induced Breakdown Spectroscopy (HR-LIBS) Applied to the Analysis of Isotopically Labelled Organic Molecules*

P25 Jiaming Li *Laser-induced breakdown spectroscopy based on fiber laser ablation (FL-LIBS) with high repetition rate and low pulse energy*

P26 Jose Miguel Vadillo *Laser-Induced Plasma Acoustics and Laser-Induced Breakdown Spectroscopy: A Happy Marriage*

P27 Kristjan Leosson *LIBS Analysis of Amorphous LLZO Films*

P28 Clothilde Comby-Zerbino *Multimodal Analysis of MALDI-MS and LIBS: Comparative Study of UV-355nm and IR-1064 nm Desorption*

P29 Elise Clavé *Plasma-atmosphere interactions in Martian LIBS and implications for carbonate characterization*

P30 Jose Miguel Vadillo *Sampling approaches based on spot aerosol generation, Catapulting and Trapping combined to LIBS*

P31 Nils Oberndorfer *Spatially Resolved LIBS Analysis of Nanoparticle Clouds Formed during Single Particle Iron Combustion*

P32 Patricia Lucena *Stand-off Spectroscopies Under Controlled Atmospheric and Temperature Planetary Conditions Using a Multipurpose Thermal Vacuum Chamber*

P33 Pravin Kumar Tiwari *Unveiling LIBS Analysis Insights: Exploring Plasma Confinement Induced by Variable Electric Fields in Both Ambient and Vacuum Environmental Conditions*

P34 Florian Mourlin *Perseverance/SuperCam LIBS technique: how to decide if a spectrum is of good quality?*

P35 Elena Santamarina *LIBS-Based Classification of End-of-Life Membrane Electrode Assemblies for Automated Sorting*

P36 Amy Bauer *Molecular Features in LIBS of Refractory Materials*

P37 Ivo M. Raimundo Jr. *Indirect determination of scaling anions in synthetic saline waters based on barium salt precipitation*

P38 Johannes Pedarnig *LIBS of aqueous solutions: Quantification of ZnSO4 transferred to paper matrix*

P39 Thuy Dung Nguyen *Laser-Induced Breakdown Spectroscopy for Elemental Mapping and Tumor Detection in Oral-Jaw Tissue*

P40 Anannya Banerjee *Modeling of Laser-Induced Heat Conduction Dynamics in Aluminum under Nanosecond Pulse Excitation*

P41 Alena Zavadilová *Application of Eye-Safe LIBS for Uranium Identification and Spatial Distribution Studies in Geological and Engineering Materials*

P42 Javier Urraca *Application of Laser-Induced Breakdown Spectroscopy (LIBS) for Rapid Detection and Determination of Mycotoxins in Food Matrices*

P43 Alena Zavadilová *Assessing Metal Contamination in Horticultural Substrates: A Dual-Pulse LIBS Approach*

P44 George Cook *Development of a miniaturised Laser induced Breakdown Spectroscopy apparatus for in-situ analysis of effluents for Nuclear Decommissioning*

P45 Jakob Von Grünberg *Laser-Based Phytomining: Real-Time Monitoring of Trace-Element Enrichment in Sweet Lupines Using LIBS*

P46 Susilo Hadi *Deuterium limit of detection estimation in 316L by picosecond LIBS and MERLIN calculation*

P47 Orsolya Urbán *Hydrogen isotope analysis in polymers by ns LIBS, fs LA-MS and µ-Raman spectroscopy*

P48 Laura García-Gómez *2D Mapping of Peridotite Analogs as Target Minerals for Martian Missions using Planetary Exploration Technologies*

P49 Luisa Cabalin *Detection of Amorphous Carbon Enclosed in Hydrothermal Gypsum Deposits by Combined LIBS and Raman Spectroscopy: Implications for Biosignature Detection in Planetary Exploration*

P50 Alejandro Ramírez *Effect of Laser Spot Size and Granulometry on LIBS Plasma Parameters in Geological Samples*

P51 Faringuisse Ehrari *Fluorine Quantification in PFAS Compounds Using a Dual Experimental and Numerical LIBS Approach*

P52 Jorge Caceres *Laser-Induced Breakdown Spectroscopy as a Cutting-Edge Tool for Identifying Plastic Composition and Verifying its Sustainable Use in the Design Field*

P53 Patricia Lucena *LIBS Implications in Planetary Exploration: The Search for Organic Biosignatures*

P54 Peter Kohns *LIBS-Detection of Harmful Metals in Plant Material*

P55 Felix Albertin *Process analysis in lithium extraction by LIBS*

P56 Camilo Prieto *Tracer-assisted polymer identification using Laser Induced Breakdown Spectroscopy*

P57 Capela Diana *Multi-Instrument LIBS Harmonization for Rare-Earth Element Imaging*

P58 Monica Dinu *Spectroscopic Pathways to Provenance: Insights into Metal Craftsmanship and Trade in Ancient Eastern Europe*

P59 Carl Basler *LIBS for quantitative Li monitoring in fluids for Li extraction and recycling*

P60 Carl Basler *Sensor for USP-Laser ablation control based on real-time plasma decay for up to 1 MHz repetition rate*

P1

Analytical Model of Crater Formation at Laser Ablation

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The analytical model of crater formation on a solid surface under laser ablation is presented. In this model, liquid layer formation, surface vaporisation and liquid matter ejection by vapor pressure are taken into account to explain the resulted crater shapes and their characteristics (depth, crater rims formation) and atomisation efficiency of laser ablation as a function of laser beam parameters (beam diameter, pulse energy and duration). The experimental results obtained in our earlier studies on laser ablation and crater formation with fs, ps and ns pulses [1-3] are discussed on the basis of this model. The limits of the model validity are discussed as well.

Keywords: Analytical model; Laser ablation; Crater formation.

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P2

Composition and depth analysis of transition metal boride using vacuum UV LIBS

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Transition metal borides are a diverse group of compounds composed of boron and a less electronegative element, typically without oxygen. Due to their technological significance, borides formed by Group 4–6 transition metals are of particular importance. These compounds exhibit extreme physical and chemical properties like a high melting point of around 3000°C, hardness over 30 GPa and elastic modulus at around 440-460 GPa, whose usage can extend from the walls of hightemperature facilities for thermal protection to structures of space vehicles [1]. These physical properties significantly depend on the concentration of Boron in the compound [2]. Laser Induced Breakdown Spectroscopy (LIBS) is a well-developed technique for on-site stoichiometric analysis of the materials. However, conventional LIBS operated in UV-near infrared (NIR) is not effective in detecting lighter elements like Boron (B) [2] whose atomic emission lines are in the vacuum ultraviolet (VUV) region. Additionally, to investigate the thermal tolerance of these compounds, a series of laser pulses is used to ablate the material. The resulting ablation crater profiles are analyzed to quantify the material removal in terms of volume [3]. The depth profile elemental analysis is done by CF approach from spectra recorded by the echelle (Michelle ME5000, Andor Technology) and VUV spectrometer (McPherson) using the NIST [4] and Kurucz atomic spectral line database [5]. The crystal structure of the samples is studied using X-ray diffraction and the ablation rates are compared against different structures to study the hardness.

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P3

LIBS signal enhancement and plasma parameter evolution: a numerical and experimental study

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The identification and quantification of trace elements within a sample by laser induced breakdown spectroscopy (LIBS) can present challenges depending on the instrumentation used. In particular, a robust analysis often requires both an intensified camera and a laser able to produces pulses that will, once focused, have an intensity ten to a few hundred times superior to the breakdown threshold of the sample. The laser-induced plasma emissivity is in fact very dependent on the latter. This is due to the fact that a more intense laser pulse typically generates a plasma with a higher temperature and electron density.

However, the relationship between the laser energy incident on the sample and the resulting plasma emissivity is highly non-linear, and varies for different emission lines. A numerical simulation was performed using the NIST LIBS database [1] to represent the line emission of Cu I at 324.8 nm and 521.8 nm respectively for different electron densities and temperatures. As shown in Fig.1.a) and Fig.1.b), plasmas with the same initial conditions and temporal evolution will exhibit different signal enhancements (integrated green path compared to integrated blue path) depending on the emission line. This insight is particularly helpful when using enhancement methods for LIBS, as these cause a change in plasma parameters compared to the reference experimental conditions [2]. In this work, a femtosecond laser is used to create microstructures on a copper sample which were found to enhance the LIBS signal due to a higher light absorption provided by the change in the surface topology.

In particular, the LIBS signal enhancement was found to greatly increase with increasing line upper energy levels.

Keywords: LIBS, Plasma emission, Simulation

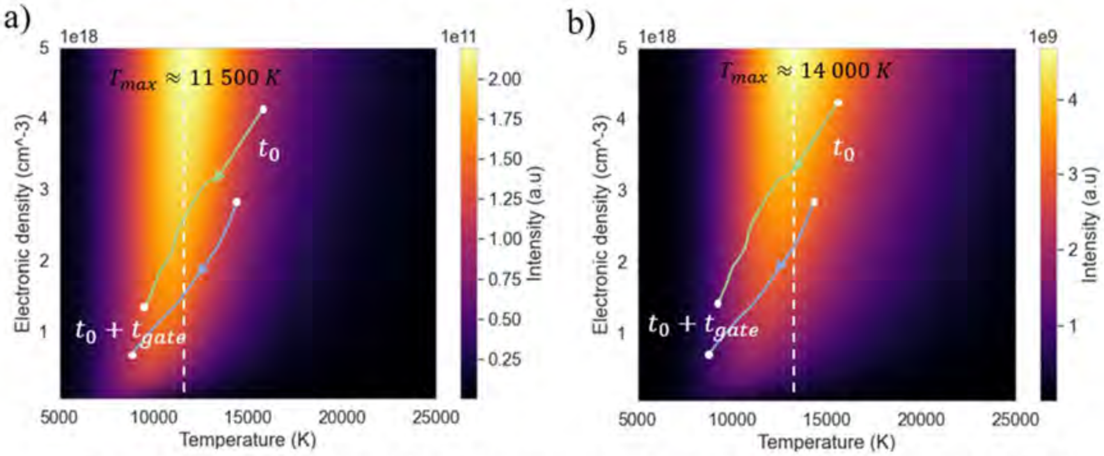

Fig 1. Numerical simulation of the LIBS line intensity of a) Cu I line at 324.8 nm and b) Cu I at 521.8 nm as a function of plasma temperature and electron density. The green and blue lines represent a hypothetical path taken by the electron density and plasma temperature during the plasma lifetime, for two different initial conditions.

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P4

Efficiency evaluation of fuel retention diagnostic in first wall by LID-QMS: Based on LIBS

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Quantifying deuterium (D) retention in plasma-facing components (PFCs) with minimal material impact is critical for fusion reactor operation. This study employs laser-induced desorption coupled with quadrupole mass spectrometry (LID-QMS) for in situ D-retention analysis on HL-3 graphite tiles. As an auxiliary strategy, laser-induced breakdown spectroscopy (LIBS) is implemented under optimized low-fluence conditions to intermittently evaluate LID-QMS desorption efficiency during operation. Laboratory experiments demonstrate >80% deuterium release in the first LID pulse (laser fluence >570 MW/m2), validated via cross-calibrated QMS measurements; LIBS provides rapid efficiency assessment by correlating D/H spectral results with QMS-resolved H, HD and D2 desorption signals. The integrated LID-QMS-LIBS framework permits: real-time optimization of LID parameters during material analysis, direct efficiency validation without destructive sampling. This methodology is currently being implemented on HL-3 tokamak for in situ wall-D monitoring, demonstrating potential to replace ex situ post-mortem analysis in future fusion devices.

Keywords: Deuterium retention; Plasma-facing components (PFC), Laser-induced desorption (LID); Quadrupole mass spectrometry (QMS); Laser-induced breakdown spectroscopy (LIBS)

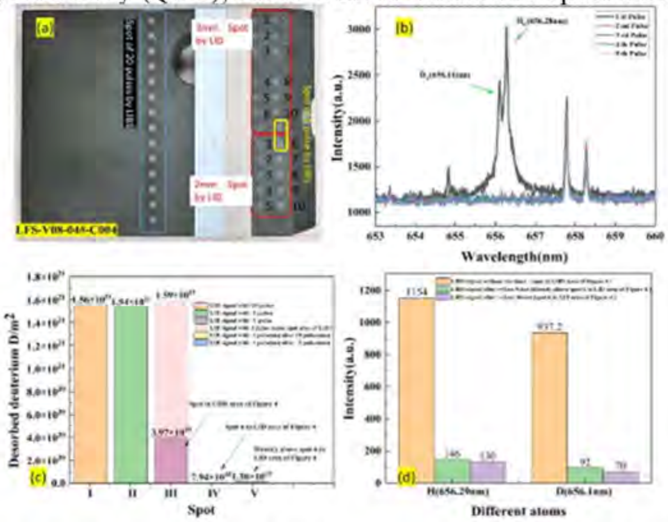

Fig. 1 (a)HL-3 first-wall graphite armor tile with measurement positions for LID-QMS (red) and LIBS (yellow);(b) Spectroscopic results of HL-3 first-wall graphite armor tile with five laser pulses;(c) QMS results of HL-3 first-wall graphite armor tile with different laser parameters;(d) Spectroscopic results of HL-3 first-wall graphite armor tile with different laser shot numbers

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P5

Fitting LIBS plasma using gradient descent

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The calibration-free LIBS (CF-LIBS) method enables the determination of quantitative plasma parameters without the need for calibration data. This can be especially useful in contexts where there is no - or not enough – matrix-matched data, such as in in-situ rover missions. Besides the indirect CFLIBS methods where plasma parameters are inferred from the spectrum directly [1], there is also the direct method where an experimentally obtained LIBS spectrum is compared to a synthetic spectrum produced by the simulation of a feasible plasma model [2].

In this work we have implemented a plasma model that is differentiable via autodifferentiation with respect to all of its parameters (e.g. temperature, elemental concentrations). We present a fitting scheme that utilizes gradient descent to find the optimal plasma parameters. Using gradients enables a speed up with respect to the “black-box” Monte-Carlo method presented in [3].
At the same time our method does not require previous expert knowledge of the target, such as selecting suitable transitions, and is able to optimize all plasma parameters simultaneously instead of iteratively [4].
In the specific case of our model, a homogeneous one-dimensional plasma at local thermal equilibrium, we demonstrate that the gradient descent approach is able to find the optimal solution fast and consistently. We show that this approach is generic and can be extended to more complex plasma models.

Keywords: Gradient Descent; Calibration-Free LIBS; Optimization;

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P6

Influence of experimental conditions on LIBS measurement sensitivity

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Keywords: LIBS; sensitivity; limit of detection; calibration-free;

The sensitivity of analytical measurements is crucial for trace element quantification. It is typically quantified via the limits of detection that are the smallest elemental fractions for which the associated analytical signal can be distinguished from the background signal [1]. In compositional measurements via laser-induced breakdown spectroscopy, the analytical signal is the spectral line emission, whereas the background signal mostly originates from the plasma continuum emission [2]. Both types of emission depend on the plasma properties, which in turn depend on the laser irradiation conditions. The limits of detection have therefore a complex dependence on the laser irradiation conditions, and it is difficult to predict the experimental conditions that enable highest LIBS measurement sensitivity.

Against this background, we determined the limits of detection for multiple elements and different sample materials by varying (i) the delay between laser pulse and detector gate; (ii) the number of laser pulses for signal acquisition; and (iii) the laser pulse energy. The measurements were performed using two different LIBS instruments. One is operated with an ultraviolet laser under argon atmosphere, the other apparatus works with an infrared laser in ambient air.

The limits of detection were obtained using a previously introduced procedure based on a calibration-free LIBS measurement method [2]. The procedure is operated using the following steps : (i) calibration-free LIBS measurements via spectra simulation [3] are applied for accurate plasma diagnostics and compositional measurements; (ii) the most sensitive transition of the elements of interest is selected via its signal to noise ratio; (iii) the curve of growth is generated for each selected line via the calibration-free approach and, (iv) the limit of detection C_{LOD} is determined by comparing the computed line intensity to the standard deviation of the background signal σ_{bg}. Precisely, C_{LOD} is given by the elemental fraction for which the line intensity equals $3\sigma_{bg}$.

In addition to the determination of the relative limits of detection C_{LOD}, we deduced the absolute limits of detection m_{LOD} defined as the minimum mass of elements required for detection. Therefore, the ablated volume is deduced from microscopic observations of the laser-produced craters. The measurements illustrate for both LIBS instruments the expected dependence of the relative limits of detection on the number of applied laser pulses $C_{LOD} \propto n_{las}^{-1/2}$. The dependence on laser pulse energy strongly differs for both LIBS systems as a consequence of stronger plasma screening in case of infrared laser radiation. The laser energy for highest sensitivity depends on the ionization stage of the emitting species and the upper-level energy of the transition.

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P7

Isotopic Fractionation in Laser Induced Plasma (LIP) Plumes

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When the laser-induced plasma (LIP) plume is examined on a spatial scale, rather than as a point source, distinct and unique emission characteristics can be identified. This spatial uniqueness arises from several factors such as preferential vaporization and ionization, plasma dynamics, and kinetic processes, which together lead to variations in particle distribution profiles within the LIP [1]. Such variations can induce both elemental and isotopic fractionation in the plume. While elemental fractionation in LIP has been addressed in earlier studies [2], isotopic fractionation remains a relatively unexplored area. A thorough understanding of isotopic fractionation trends is crucial for developing or refining reliable isotopic analysis techniques based on the LIP, such as Calibration-Free Laser Ablated Molecular Isotopic Spectrometry (CF-LAMIS) [3]. The present study aims to investigate isotopic fractionation trends within a boron LIP plume using the CF-LAMIS methodology.

The analysis revealed spatial variations in the molecular emission band heads of ^{11}BO and ^{10}BO. The ^{11}BO band head was observed closer to the sample surface, while the ^{10}BO band head became more prominent with increasing height above the surface, the ^{10}BO band head became more prominent. These observations point to significant isotopic fractionation occurring within the plume. Near the sample surface, the ^{10}B isotopic composition was relatively lower compared to the actual abundance, but progressively increased with plume expansion as illustrated in Fig. 1. This trend indicates that isotopic fractionation evolves progressively as the plasma propagates outward. A detailed examination of the lateral plume profile further revealed that the heavier isotope, ^{11}B, was enriched near the sample surface, whereas the lighter isotope, ^{10}B, became more concentrated in the outer plume regions. This behavior implies preferential migration of ^{10}B with the expanding plasma front, likely driven by shockwave-induced dynamics during laser ablation. Temporal analysis also showed that isotopic fractionation was more pronounced at earlier delay times, corresponding to the active expansion phase of the LIP. In addition, the influences of ablation wavelength and ambient atmosphere were systematically examined, further highlighting their roles in shaping isotopic fractionation profiles. The results from this study provide valuable new insights into isotopic behavior within LIP plumes, contributing to the optimization of LIP based techniques for precise isotopic measurements.

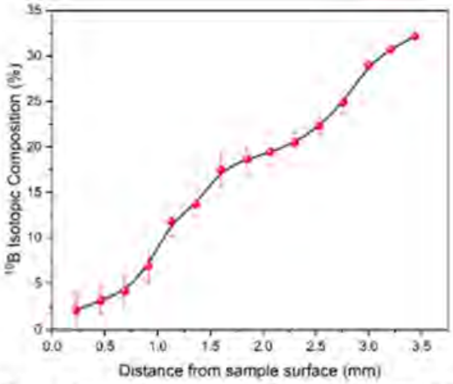

Fig. 1 Isotopic fractionation in boron LIP

Keywords: Isotopes; Fractionation; Boron; CF-LAMIS.

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P8

Quantification of matrix effects observed in LIBS analysis of metal alloys

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As a direct solid analysis technique combining sampling and excitation of the material by laser ablation, LIBS is subject to matrix effects. These effects result in variations in ablated mass, temperature, and plasma density from one material to another. They are therefore essential to characterize when dealing with different types of matrices. Certain quantification methods, such as the well-known CFLIBS, allow them to be corrected based on spectroscopic measurements of plasma characteristics [1]. However, these measurements are subject to uncertainties related to spectroscopic parameters such as the Stark broadening parameter or the Einstein coefficient of the transition, and/or measurement biases due, for example, to self-absorption.

Here, we are interested in accurately characterizing the matrix effects observed in a model case, namely the analysis of impurities in metal alloys. To do this, we use a method described in previous work, in which a tracer element is deposited on the surface of the samples [2]. Iron is chosen because it allows the temperature and electron density of the plasma to be measured. The deposit is made in such a way that it has only a marginal, or even negligible, influence on ablation and plasma parameters. The ablated mass is then measured by an interferometric profilometer. The temperature is determined by a Boltzmann plot, with particular attention paid to the choice of lines limiting measurement bias. Finally, the electron density is estimated in the conventional manner by measuring the Stark broadening.

We will discuss the measurements of these three parameters characterizing matrix effects, and we will present calibrations of iron concentration in seven metal alloys, corrected for variations in ablated mass, plasma temperature, and density. The results show that matrix effects can be satisfactorily corrected for four of them. The discrepancies observed for the others will also be discussed. Differences in crystal structure and vaporization yield of the ablated material may be invoked to explain these discrepancies.

Keywords: matrix effects; quantitative analysis; metal alloys

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P9

Elemental analysis of liquids using LIBS acoustic levitation in different stages of CW laser drying

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The elemental analysis and trace elements detection in liquids is studied using Laser-Induced Breakdown Spectroscopy (LIBS). The challenges of analyzing liquids arise due to unclear anomalous processes of the laser pulse-liquid interactions, and also due to the strong quenching of laser induced plasma (LIP) by the water molecules and its radicals. To overcome these problems studies with different LIBS techniques were carried out [1-2]. Recently LIBS assisted by acoustic levitation (LIBS-AL) has been used with CW laser drying for preconcentrating an isolated droplet before LIBSAL analysis [3-5]. This technique allows methods such as calibration curve (CC) by external standard to quantify difficult elements such as Boron in water samples [4] or Calibration-free (CF) quantification of mineral waters samples [5]. Some recent results have shown applicability of LIBSAL technique for CC quantification of Fe in plasma activated water samples (PAW) due to the contamination during production of PAW. This contribution studies CW laser drying process in time to optimize proposed LIBS-AL technique. The goal is to observe the evolution of LIBS spectra quality and CF quantification of elements within water-based matrix during different stages of preconcentration/drying by CW laser. LIBS spectra were recorded using a broadband echelle spectrometer (Andor Tech., ME5000) coupled to an iCCD (Andor Tech., iStar DH734).

Keywords: liquid sample quantification, LIBS-AL, CW laser drying, preconcentration

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P10

Wavelength Drift Correction Method for Laser-Induced Breakdown Spectroscopy Based on Phase Correlation

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Laser-Induced Breakdown Spectroscopy (LIBS) technology faces significant challenges from wavelength drift caused by temperature variations in practical applications, which severely affects the accuracy and reproducibility of spectral analysis. This paper proposes an efficient correction algorithm based on phase correlation method to address the wavelength drift problem in LIBS systems caused by temperature changes. The method utilizes the shift theorem of Fourier transform to perform correlation operations on the entire spectral frequency domain, enabling rapid and accurate estimation of overall spectral drift without requiring peak-by-peak matching, thereby avoiding error accumulation and computational complexity associated with traditional methods. Experimental results demonstrate that within the temperature range of 20℃ to 34℃, spectral drift shows a significant linear increase with rising temperature, with notable differences in drift magnitude across different spectral channels. After correction using the proposed method, wavelength correction errors for all channels are controlled within 0.01 nm, with an average correction error of 0.0034 nm, achieving sub-pixel precision correction. Compared with existing wavelength correction technologies such as the PSO and MGR algorithms on the MarSCoDe LIBS system, this method offers higher computational efficiency, lower hardware costs, and better adaptability. The research provides a reliable and economical solution for the industrialization and commercialization of LIBS technology, demonstrating significant practical value and application potential.

Keywords: LIBS; Wavelength Drift; Phase Correlation.

P11

Calibration-free LIBS analysis of Diatomite for High Purity Silicon Extraction

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The production of high-performance silicon, particularly for photovoltaic applications, critically depends on the purity of diatomite used as the raw material. Even trace contaminants in diatomite can significantly degrade the quality of the extracted silicon, compromising the efficiency and long-term reliability of silicon-based solar technologies. In this study, we present an enhanced Calibration-Free Laser-Induced Breakdown Spectroscopy (CF-LIBS) approach optimized for high sensitivity to perform a comprehensive elemental characterization of diatomite [1]. The method employs dual spectral acquisition at distinct gate delays to extend detection capabilities across a wide range of elements, from major constituents to minor and trace impurities.

Detection limits were rigorously evaluated, confirming the technique's precision and suitability for impurity quantification. Complementary analyses using Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDX) provided additional insights into the material's morphology and elemental distribution [1]. Together, these analytical techniques establish a robust framework for assessing diatomite quality and optimizing silicon extraction processes.

Keywords: Calibration-free LIBS; Diatomite; Impurity Analysis; Limits of detection.

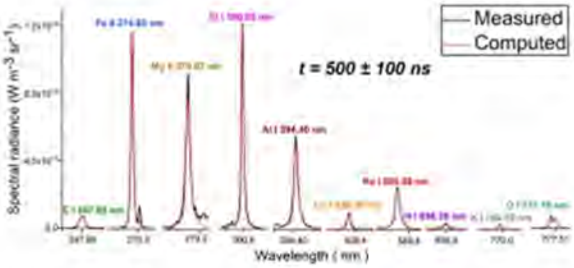

Fig. 1 Measured and computed spectra of the early diatomite plasma showing major elemental emission lines [1].

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P12

Can LIBS explain the color of a sample?

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The images obtained through Laser Induced Breakdown Spectroscopy (LIBS) are highly valuable in many disciplines, especially in geology. They offer a clear representation, with micrometric precision, of the relative concentration of elements present within a sample. When the sample under study is a rock, the data from LIBS allows for the determination of the major mineral phases, often employing clustering techniques. While these representations are precise, they are not necessarily intuitive for the user, whose initial perception relies on the petrography of the sample—specifically its shape and color. This study thus proposes implementing a feedback loop aimed at intuitively establishing a correspondence between the LIBS signals and the observed color. The goal is to reconstruct the color of the rock surface based on the different LIBS images, particularly for a carbonate from the Dalle aux ammonites of Digne-les-Bains (Fig. 1). The dual benefits of this reconstruction are as follows: it enables the identification of major elements for which color serves as a relevant indicator, and it provides the opportunity to analyze areas where the elemental concentrations measured by LIBS are insufficient to explain the observed color variations, which may be linked to the sample's mineralogy or isotopic variations [1]. As seen in Figure 1, the various textural effects, such as those related to surface roughness, are no longer visible. This significant loss of information results from structural phenomena that are not captured by the LIBS images; only substantial color variations are reconstructed from the LIBS data: mudstone (homogeneous black areas), wackestone (heterogeneous black areas), and calcite (white areas).

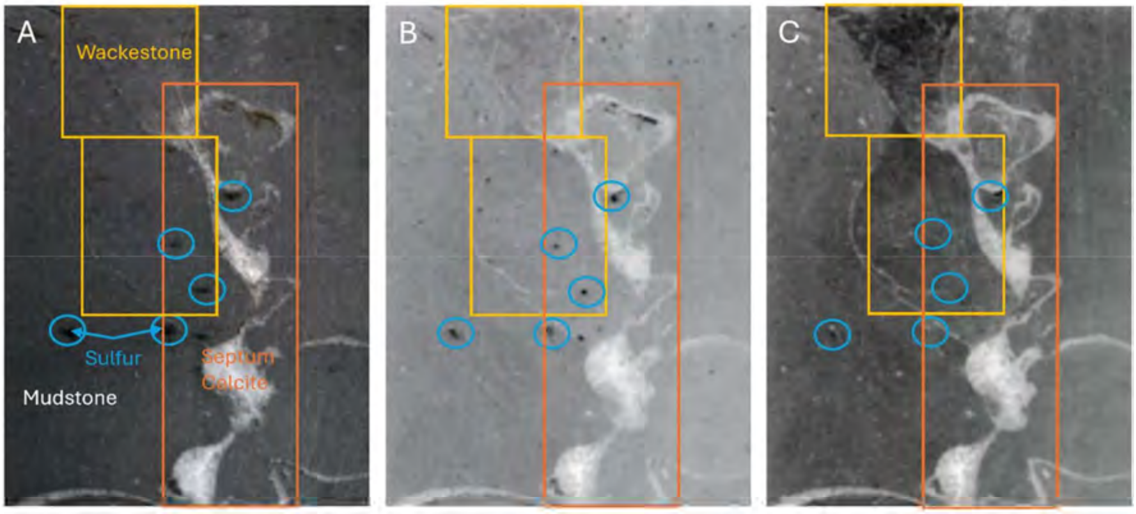

Fig. 1 In A, a photograph of a carbonate from the Dalle aux ammonites of Digne-les-Bains, in B the image reconstruction based on four elements (Al, Mg, Mn and O), and in C with two elements (Mn, O).

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P13

Multielemental quantification by CF-LIBS assisted by a deep learning model trained on simulated spectra

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Keywords: LIBS quantification; Deep learning; Simulated spectra; Duralumin

CF-LIBS (Calibration-Free Laser-Induced Breakdown Spectroscopy) enables element concentrations to be determined without calibration [1]. It can be done using simulated emission spectra, and therefore requires the simulation of radiative transfer, considering line profile broadening caused by various physical phenomena (Doppler effect, Stark effect, apparatus function, etc.). Fast comparison between experimental and simulated spectra can be performed using artificial intelligence, including deep learning from labeled data [2]. Successful learning of the network relies mainly on the database, which must be large enough in terms of number of spectra to cover the full range of possible conditions. However, assembling millions of labelled experimental spectra, i.e. spectra whose plasma parameters and emitter proportions have already been determined, is a time-consuming and demanding task. For this reason, the database can be simulated using the modeling tools developed for CF-LIBS [3, 4, 5]. We present the results of a multi-species quantification test case using a deep learning tool called ELIAS (Efficient Learning for Inference and Analysis of Spectra). The process is as shown in figure 1. Training and tests are performed using over a million simulated spectra generated by the MERLIN (MultiElemental Radiative equiLibrIum emissioN) code which simulates LIBS spectra at Local Thermodynamic Equilibrium (LTE) [6]. Spectral radiances are processed by a deep neural network enabling the prediction of homogeneous plasma composition and physical variables (electron density, temperature). Results from the validation of the numerical tool will be presented, and an initial comparison with experimental spectra will be discussed.

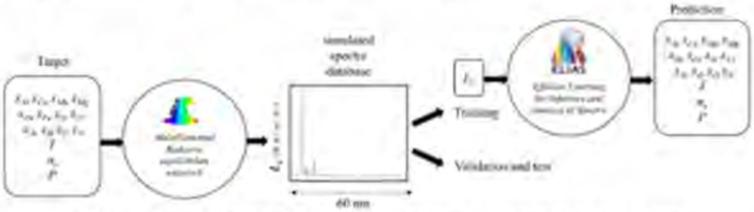

Fig. 1 Overall approach from database creation to training

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P14

Multiparametric processing of LIBS spectra of lowalloy steels

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This work is devoted to the application of laser-induced breakdown spectroscopy (LIBS) for the quantitative determination of three chemical components (carbon (C), manganese (Mn), chromium (Cr)) in low-alloy steels using multiparametric spectral processing methods.

Figure 1 shows a schematic of the setup used in this study. Plasma was generated by a focused beam of fundamental harmonic of Nd:YAG laser (LOTIS TII, Belarus), pulse duration: 10 ns, pulse energy 80 mJ. A compact spectrometer was used to record the emission spectra. The recording system parameters were: spectral range 190–440 nm, spectral resolution 0.4 nm.

The objects used for spectral measurements were sets of reference samples of low-alloy steels.

Both univariate and multivariate statistical models were used to process the raw lowresolution spectra. ElasticNet and Partial Least Squares Regression (PLS-R) were used as multiparameter methods for processing the emission spectra. R^2 and RMSE (Root Mean Square Error) were used as metrics to evaluate the quality of the regression model. The results obtained by various analysis methods were evaluated and compared. For single-parameter calibration, the following wavelengths were used: 247.85 for carbon, 259.37 for manganese, and 309.58 for chromium. The single-parameter calibration was characterized by unsatisfactory quality ($R^2_C<0.4$, $R^2_{Mn}=0.91$, $R^2_{Cr}=0.76$). The results confirm the effectiveness of the multivariate LIBS analysis for determining element concentrations in low-alloy steel samples: C (0.05 - 1.32%, $R^2_C=0.76$), Mn (0.08-1.97%, $R^2_{Mn}=0.985$), Cr (0.04-2.85%, $R^2_{Cr}=0.986$).

Keywords: Laser Ablation; Laser-Induced Breakdown Spectroscopy; Laser Spectral Analysis; Mathematical Statistics.

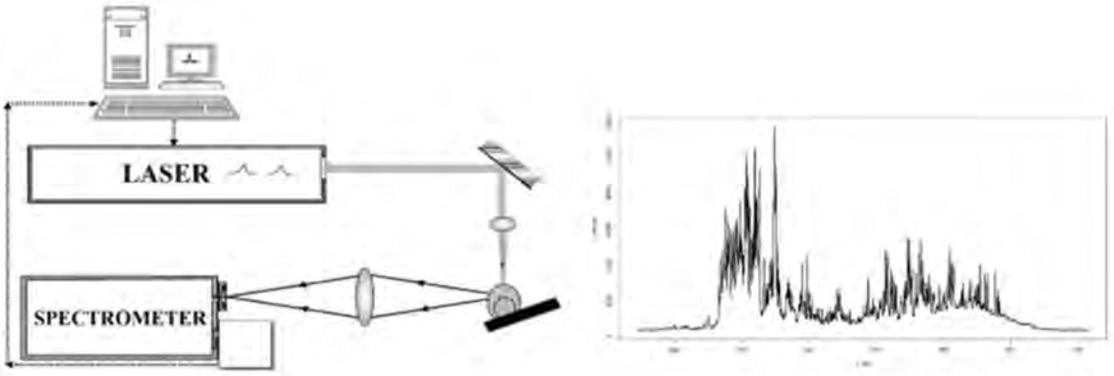

Fig. 1 Experimental setup and typical emission spectrum of low-alloy steel sample

P15

Unveiling mineral phase distribution in the Chelyabinsk LL chondrite using LIBS mapping and cluster analysis

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The Chelyabinsk meteorite was analyzed using Laser-Induced Breakdown Spectroscopy (LIBS) combined with Raman spectroscopy to characterize chemical and mineralogical heterogeneity across its inner matrix, fusion crust, and metallic inclusions. LIBS spectra acquired at selected points revealed major elements including Fe, Mg, Si, Al, Ca, Cr, Mn, Na, and Ni. Relative intensity ratios normalized to Fe confirmed a higher abundance of rock-forming silicates in the inner matrix, Fe-rich metallic inclusions, and intermediate compositions in the fusion crust. High-resolution LIBS mapping (100 µm) visualized the spatial distribution of mineral phases, with Na + Ca highlighting plagioclase, Fe + Mg olivine and pyroxene, Cr chromite, and Fe + Ni metallic phases. K-means clustering integrated the elemental maps into a single classification, clearly distinguishing five mineral phases. Calibration-Free LIBS (CF-LIBS) was applied at strategically selected points to determine semi-quantitative elemental compositions. A ternary diagram based on the CF-LIBS-derived oxide percentages (FeO–MgO–SiO_2) confirmed the classification of Chelyabinsk as an LL-type ordinary chondrite. This workflow demonstrates that LIBS mapping combined with clustering and CF-LIBS allows rapid, minimally invasive assessment of meteorite heterogeneity, mineral distribution, and classification, providing detailed microscale compositional information while preserving the integrity of rare samples.

Keywords: LIBS mapping; CF-LIBS; K-means cluster analysis; Raman

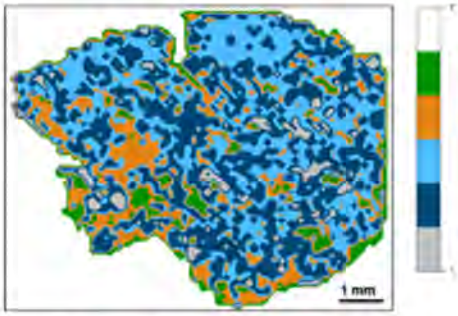

Fig. 1 K-means clustering map (K = 6) based on elemental composition, illustrating the different mineral phases of the Chelyabinsk meteorite.

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P16

Use of Rank Transformation to Correct Flatness Defects in High-Resolution LIBS Imaging

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Images derived from Laser Induced Breakdown Spectroscopy (LIBS) are of significant interdisciplinary interest as they provide the relative concentration of elements across a sample. These images are generated by scanning the sample surface pixel by pixel, with each pixel corresponding to one or more LIBS spectra. Therefore, LIBS images are highly sensitive to experimental conditions, such as sample preparation. For example, a defect in the flatness of the sample surface can alter the orientation of the plasma, and thus the amount of collected light; such a defect, if present in a LIBS map, is challenging to correct. The spectra may then be considered biased, and the collected intensity levels become difficult to utilize effectively. To address this issue, we propose the use of rank transformation [1]. The rank transformation process involves assigning a ranking to each intensity value. The minimum intensity is assigned a rank of 1, the second smallest a rank of 2, and so on. This ranking is then used when applying Principal Component Analysis (PCA). Thus, the analysis is conducted not on the intensity values themselves, but on their ranks. We propose to apply and examine the effects of this transformation (Fig. 1) on a calcium carbonate sample that includes a polishing defect.

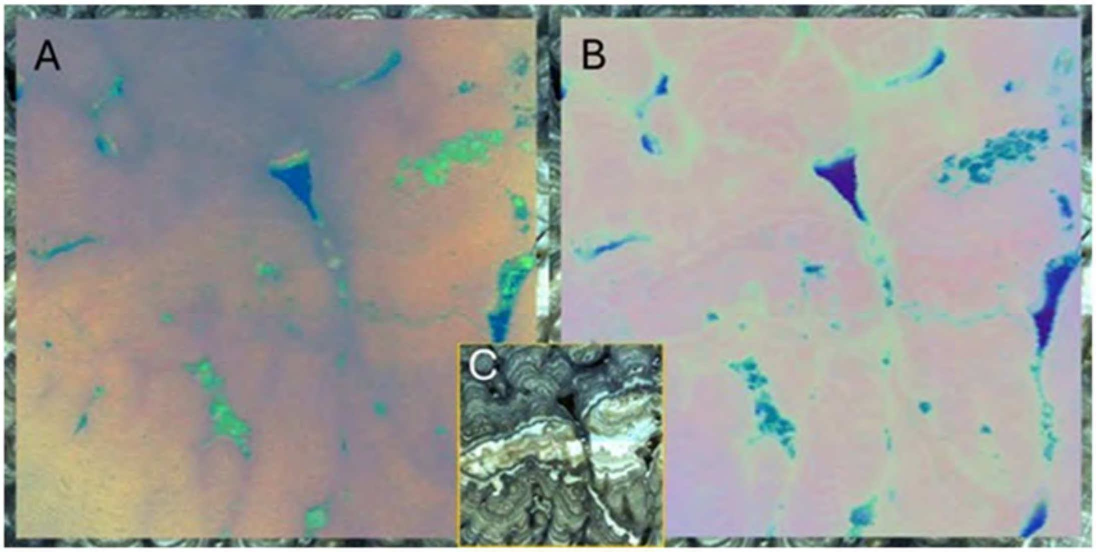

Fig. 1 False-color images of the first three PCA components obtained: A without applying any transformation, B with the rank transformation applied, and C showing a photograph of the calcium carbonate sample.

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P17

A Python application for processing LIBS spectra

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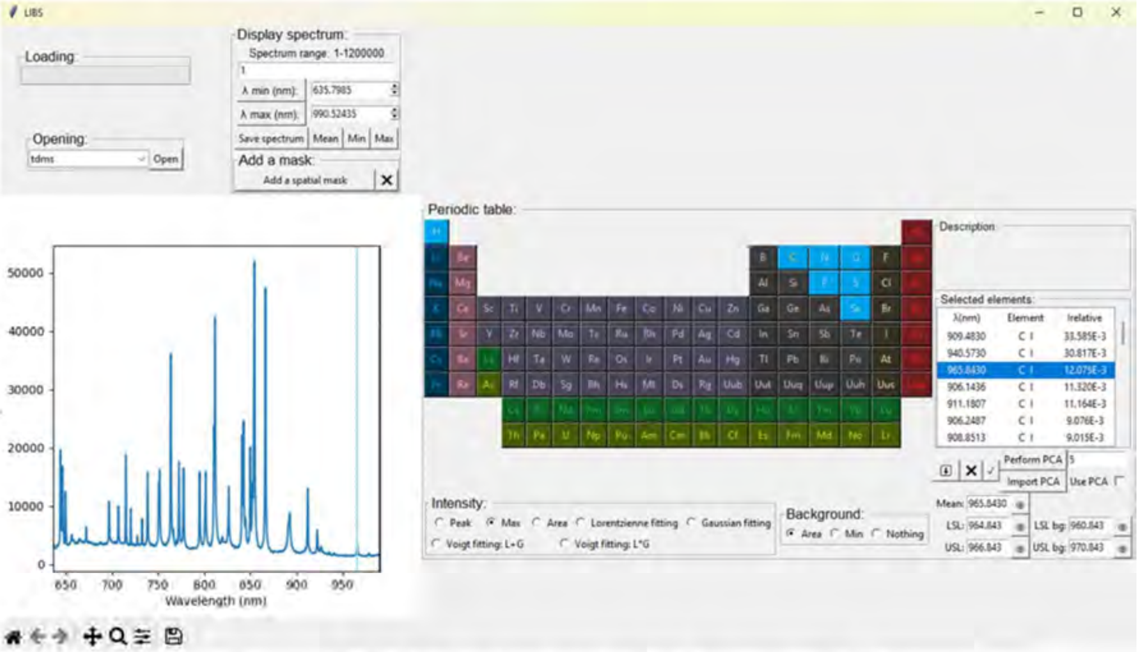
The mathematical fitting of spectral lines using models is challenging to achieve in high-resolution LIBS imaging, as this fitting must strike a balance between speed and reliability to process billions of spectral lines and construct a LIBS image. As a result, most studies do not perform fitting but rather calculate sums or differences of intensity levels [1], meaning the spectral lines are treated as Dirac functions. We propose a Python 3.12-based application (Fig. 1) designed to process LIBS spectra using various line-fitting models. These fitting models account for the physical contributions to the observed spectral profiles, which are related to plasma-specific physical phenomena, such as their temperature or electron density, along with instrumental functions. The proposed fittings include Lorentzian, Gaussian, or Voigt profiles. Additionally, this application offers various statistical tools for comparing the performed fittings, managing the background light, and more generally handling noise measurement, thus producing images tailored to the user's needs. This application is freely available for download at: https://github.com/ICBAlban/LIBS.git



tdms

Spectrum range: 1-1200000

1

λ min (nm): 635.7985

λ max (nm): 990.52435

λ(nm)	Element	Irelative
909.4830	C I	33.585E-3
940.5730	C I	30.817E-3
965.8430	C I	12.075E-3
906.1436	C I	11.320E-3
911.1807	C I	11.164E-3
906.2487	C I	9.076E-3
908.8513	C I	9.015E-3

Perform PCA: 5

Intensity: ○ Peak ● Max ○ Area ○ Lorentzienne fitting ○ Gaussian fitting ○ Voigt fitting: L+G ○ Voigt fitting: L*G

Background: ● Area ○ Min ○ Nothing

Mean: 965.8430

LSL: 964.843

USL: 966.843

LSL bg: 960.843

USL bg: 970.843

Fig. 1 User interface of the Python-developed application for processing LIBS measurements.

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P18

Advancements in Polymer Type Determination in the Plastic Industry using Sci-Trace/M-Trace LIBS Technology

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Laser Induced Breakdown Spectroscopy (LIBS) has emerged as a promising analytical technique for the plastic industry, offering the capability to measure plastic materials directly, even inline with minimal or no sample preparation. This approach has gained significant attention due to the increasing necessity for quality control in the recycling process, ensuring the purity and composition of recycled plastics [1,2]. This study explores the application of LIBS for analyzing various plastic types, including polypropylene (PP), copolymer polyethylene/polypropylene (copoPE+PP), polyethylene (PE) polystyrene (PS), and polyethylene terephthalate (PET), in the form of recycled flake forms.

The spectra of plastic samples were analyzed, highlighting key elements such as carbon (C), oxygen (O), nitrogen (N), and hydrogen (H), as well as common contaminants such as copper (Cu), iron (Fe), titanium (Ti), sodium (Na), and potassium (K). Principal Component Analysis (PCA) was employed to assess data clustering, revealing distinct patterns for PP flakes and outliers, based on an average of 125 spectra per sample. Further, multiple machine learning algorithms were applied for polymer-type classification, with varying training datasets, and the results of the prediction scatter are discussed. Additionally, the detection of chlorine, notably from CaCl bands adjacent to CaO, and the presence of harmful elements such as barium (Ba) in granulate and recycled shreds were successfully identified, which is critical for ensuring the safety and quality of recycled plastics. This work demonstrates the potential of LIBS as a robust tool for efficient and non-destructive, respectively micro-destructive monitoring in plastic recycling processes, contributing to higher standards in material quality assurance and contamination detection.

Keywords: LIBS; Polymers; Classification

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P19

Cross-Instrument Data Utilization Based on Laser-Induced Breakdown Spectroscopy (LIBS) for The Identification of *Akebia* Species

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New technologies and equipment for medicine analysis and diagnostics have always been critical in clinical medication and pharmaceutical production. Especially in the field of traditional Chinese medicine (TCM) where the chemical composition is not fully clear, cross-device analysis and identification using the same technology can sometimes even lead to misjudgments. Akebia species, capable of inducing heat clearing, diuresis, and anti-inflammatory effects, show great potential in clinical applications. However, the three commonly used species differ in pharmacological effects and therefore should not be used interchangeably. We proposed a method combining LIBS with random forest for species identification and established a modeling and verification scheme across device platforms. Spectra of three Akebia species were collected using two LIBS systems equipped with spectrometers of different resolutions. The data acquired from the low-resolution spectrometer were used for model training, while the data from the high-resolution spectrometers were used for testing. A spectral correction and feature selection (SCFS) method was proposed, in which spectral data were first corrected using a standard lamp, followed by feature selection via analysis of variance (ANOVA) to determine the optimal number of discriminative features. The highest classification accuracy of 80.61% was achieved when 28 features were used. Finally, a post-processing (PP) strategy was applied, where abnormal spectra in the test set were removed using density-based spatial clustering of applications with noise (DBSCAN), resulting in a final classification accuracy of 85.50%. These results demonstrate that the proposed "SCFS-PP" framework effectively enhances the reliability of cross-instrument data utilization and expands the applicability of LIBS in the field of TCM.

Keywords: laser-induced breakdown spectroscopy; traditional Chinese medicine; spectral correction.

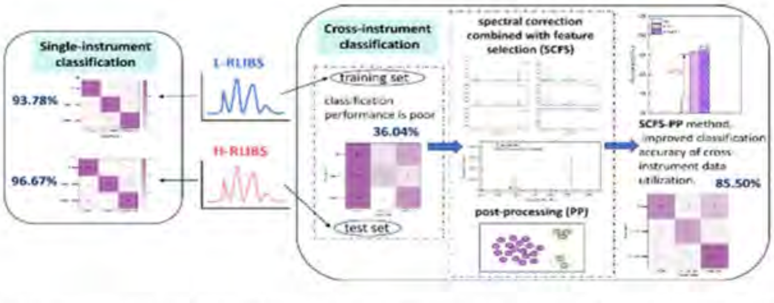

Fig. 1 The main process and results of cross-instrument data utilization for the identification of *Akebia* species.

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P20

Determination of sulfides by HSI coupled with μ-LIBS and their use as a pathfinder to gold mineralization

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The Chilean copper industry generates a wide variety of mineralized rocks whose compositional variability strongly influences the recovery of economically valuable metals such as gold [1,2]. In this context, mineralogical characterization represents a crucial step in the mining value chain, where advanced techniques such as Laser-Induced Breakdown Spectroscopy (LIBS), Raman spectroscopy, and Hyperspectral Imaging (HSI) play an increasingly important role. In this study, representative rock samples were first characterized by an expert geologist to establish mineralogical references. Subsequently, two-dimensional elemental and spectral analyses were carried out using HSI as a rapid screening method, followed by LIBS for elemental confirmation and Au identification. The combined approach enabled spatially resolved chemical mapping and clear discrimination between mineral phases. Through spectral feature analysis, HSI successfully differentiated oxide and sulfide phases, revealing marked contrasts in their spatial distribution [2]. LIBS analysis provided complementary elemental maps of major elements such as Cu, Fe, and S. Furthermore, micro-LIBS measurements allowed the detection and localization of gold signals associated with sulfide phases, particularly in chalcopyrite- and borniterich domains. These findings highlight the potential of integrating HSI and LIBS for nondestructive, high-resolution mineral characterization in complex ore systems. The synergy between geological expertise, hyperspectral visualization, and μ-LIBS mapping offers a promising strategy for the rapid identification of gold-bearing zones within copper deposits, contributing to more efficient mineral exploration and process optimization in the Chilean mining sector. This integrated approach could also support the development of future on-site analytical devices for valuable elements.

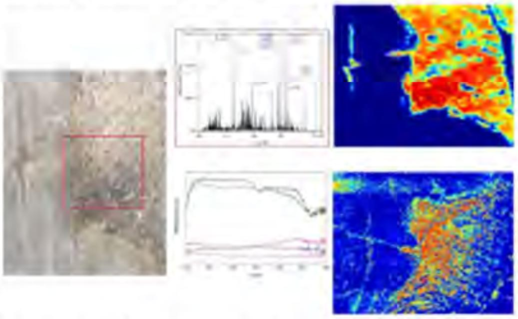

Fig. 1. HSI and LIBS imaging of a rock sample.

Keywords: μ-LIBS, Sulphur-based minerals, Copper, Gold

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P21

Effect of Particle Size on LIBS Emission and Structural Characteristics of Iron-Based Soils

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Abstract

Laser-Induced Breakdown Spectroscopy (LIBS) is an optical emission technique in which a high-energy laser pulse is focused onto the surface of a material, producing a transient micro-plasma. As the plasma cools, it emits light containing the characteristic spectral lines of the constituent elements, allowing direct and simultaneous multi-elemental analysis. LIBS offers several advantages over conventional analytical methods, including minimal or no sample preparation, rapid analysis , and the capability to perform in situ and real-time measurements on solids, liquids, or gases materials. However, the analytical performance of LIBS is not governed solely by chemical composition; it is also highly sensitive to physical and microstructural factors such as particle size, surface roughness, and compaction, which can influence plasma formation, energy coupling, and emission intensity. In complex granular materials like soils, the role of particle size in modulating light absorption, scattering, and plasma formation remains poorly understood. Variations in granulometry can significantly alter photon coupling efficiency and signal reproducibility, thereby affecting quantitative interpretation. This study provides the assessment of granulometric effects on LIBS plasma behavior and emission characteristics in iron-rich Algerian soils.

To strengthen, to provide deeper insight into LIBS mechanisms, X-ray diffraction (XRD) and Raman spectroscopy were employed as complementary methods to correlate optical and plasma behavior with structural and vibrational properties. Iron-rich soil samples with particle sizes ranging from 32 to 125 µm were investigated. XRD patterns showed identical peak positions across all fractions, confirming stable crystalline phases, while finer grains exhibited broader peaks due to smaller crystallite size and enhanced microstrain. Raman spectra displayed consistent vibrational modes, although the signal intensity decreased for smaller grains owing to increased scattering and defect-induced damping . LIBS analyses revealed higher emission intensities for larger particles, indicating more efficient plasma generation in less compacted samples .

These results demonstrate that particle size, though chemically neutral, critically governs the optical and plasma processes defining spectroscopic response. Controlling granulometry and compaction is therefore essential for quantitative accuracy in XRD, Raman, and LIBS analyses of heterogeneous soil systems.

Keywords : LIBS ; Particle size ; Iron-based soils ; XRD ; Raman Spectroscopy.

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P22

Accurate Laser Spot Characterization for Enhanced Micro-LIBS Imaging via Knife-Edge Profiling

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Accurate characterization of the laser beam profile remains a major challenge in micro-LIBS (Laser-Induced Breakdown Spectroscopy). In many cases, the crater diameter produced on the sample surface is significantly larger than the theoretical laser spot size [1,2], making a precise estimation of key ablation parameters such as fluence difficult.

In this work, we propose a robust methodology to accurately determine the laser spot size using a variant of the Knife-Edge method, commonly employed for laser beam profiling. The beam diameter was extracted by fitting the experimental edge response with an error-function model, providing the Gaussian beam parameters, including the 1/e² and FWHM diameters [3]. A custom bifacial sample composed of copper and steel with a sharp interface was used for this analysis, yielding a FWHM of 1.6 µm. This optical characterization was then used to construct the point spread function (PSF) required for Richardson–Lucy deconvolution of LIBS intensity maps. Applying this approach to the copper side of the bifacial sample, with a lateral resolution of 1 µm, significantly enhanced spatial fidelity, reduced signal spreading, and improved the sharpness of micro-LIBS images while preserving their quantitative integrity (see Figure 1).

Keywords: Laser beam profiling; Knife-edge method; Spot size measurement; Micro-LIBS.

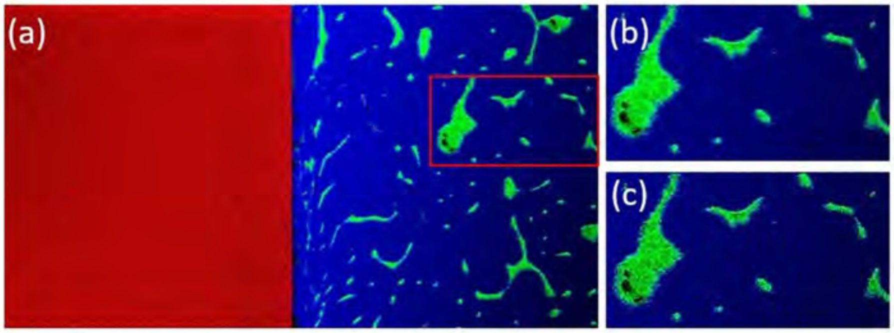

Figure 1: (a) Composite natural image of Fe (red), Cu (blue) and Pb (green) at 1 µm lateral resolution of the bifacial sample. (b) Zoom of the composite natural image. The specific area is represented by the red rectangle. (c) Deconvoluted composite zoomed image by Richardson-Lucy (RL) method. The number of iterations used in the RL deconvolution was 5.

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P23

High-Resolution Laser-Induced Breakdown Spectroscopy for Micron-Scale Geomaterial

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The micro-LIBS imaging approach has so far been implemented with lateral resolutions typically ranging from 10 to 20 µm. However, advancing toward higher spatial resolutions [1] while maintaining a sufficient LIBS signal to detect minor and even trace elements has become essential. Such ultra-high-resolution capability is particularly valuable in geological applications, where both the detection of light elements and strategic metals provide crucial insights into mineralization processes and rock microstructures. This technique directly links elemental composition to the microscopic organization of mineral phases, offering key information on formation and alteration mechanisms within geological systems.

In this context, a new high-resolution LIBS system has been developed. The setup employs a green laser (532 nm) with adjustable attenuation and optical filtering to achieve the smallest spot sizes. It is coupled to piezoelectric stages with optical encoders ensuring sub-micrometer positioning accuracy and exceptional mechanical stability during scanning. In this poster, we present this unique LIBS system, which combines 1 µm spatial resolution with a fast acquisition rate of 50 Hz. This unprecedented configuration merges micrometric precision with high throughput, enabling rapid analysis of heterogeneous materials. Preliminary results obtained on various geological samples, including gold mineralization zones and As–Pb–Zn phase transitions, demonstrate the instrument's outstanding potential for future applications in geoscience and mineral analysis.

Keywords: Micrometrical Resolution; Gold mineralization; Mineral phases; Micro-LIBS.

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P24

High-Resolution Laser-Induced Breakdown Spectroscopy (HR-LIBS) Applied to the Analysis of Isotopically Labelled Organic Molecules

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Laser-induced breakdown spectroscopy (LIBS) is a versatile analytical technique that can provide elemental and molecular information in real time. It is applicable to various fields, including planetary exploration [1,2], environmental analysis and materials science. The development of high-resolution LIBS (HR-LIBS) significantly improves the ability to resolve fine spectral details, including isotopic shifts. These shifts are of particular interest in astrobiological studies aimed at identifying biosignatures on Mars.

This work focuses on characterizing HR-LIBS spectra of isotopically labelled organic molecules, paying particular attention to the diatomic CN and C_2 fragments, which are potential molecular biosignatures. This study compares LIBS spectra obtained under two different environmental conditions — terrestrial air and a simulated Martian atmosphere (CO_2 at 7 mbar) — to evaluate the effect of surrounding gas composition on plasma formation and molecular emission.

Samples of urea and benzamide, as well as their enriched ^{13}C and ^{15}N isotopologues, were prepared in pellet form and analyzed using an Nd:YAG laser (1064 nm) and a high-resolution Echelle spectrograph. Emission spectra were recorded in the ultraviolet–visible region, focusing on the CN violet system ($\Delta v = 0$ and $+1$ transitions) and the C_2 Swan bands. Isotopic shifts between the $^{12}C^{14}N$–$^{13}C^{14}N$ and $^{12}C^{14}N$–$^{12}C^{15}N$ isotopes were measured for the first time at high resolution.

The results reveal that molecular emission intensities are higher in air than in CO_2, due to the availability of atmospheric nitrogen in CN formation. The observed isotopic shifts in HR-LIBS spectra are in the order of picometers, which confirms the necessity of using high-resolution instrumentation to distinguish them accurately. Furthermore, simulated spectra generated using commercial software were employed to validate the calibration and spectral resolution of the experimental setup.

This study demonstrates the potential of HR-LIBS as a powerful analytical tool for isotopic and molecular analysis relevant to astrobiology and the search for life on other planets. The ability to detect and resolve isotopic molecular signatures such as CN and C_2 under Martian-like conditions reinforces the applicability of LIBS in upcoming space missions.

Keywords: HR-LIBS, isotope shift, high-resolution spectroscopy, CN, C_2, biosignatures, Martian atmosphere.

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P25

A calibration-free method for laser-induced breakdown spectroscopy based on a high-repetition-rate fiber laser and non-gated detectors

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The combination of laser-induced breakdown spectroscopy based on fiber lasers (FL-LIBS) and non-gated detectors take advantages of cost-effective, fast response, and stable long-term operation, has great potential for rapid detection and online diagnosis. However, conventional calibration-free (CF) method struggle to achieve satisfactory analytical accuracy in FL-LIBS measurements with such detectors. This is because the plasma properties certainly change during the acquisition time which is much longer than plasma lifetime. Therefore, this work develops a novel calibration-free method to address the limitations in FL-LIBS using non-gated detectors. The methodology comprises two principal components: spectra simulation via time-integration method and determination of unknown parameters utilizing particle swarm optimization (PSO); hence, the new calibration-free method is designated as PSO-SSCF. Overall, it exhibits superior accuracy on the quantitative analysis of standard TC4 titanium alloys. Compared to conventional CF method, reductions in average relative errors (AREs) range from 1.539% to 7.631% for aluminum, 22.631% to 29.173% for vanadium, and -1.071% to 0.714% for titanium. PSO-SSCF even outperforms the time-integrated calibration-free (TICF) method with an iCCD gated detector. Moreover, PSO-SSCF shows good repeatability with relative standard deviation (RSD) less than 5%, and achieves sub-second computation time via GPU acceleration. In a summary, this work provides a feasible calibration-free method for FL-LIBS, facilitating the application of LIBS in scientific and industrial fields.

Keywords: laser-induced breakdown spectroscopy; fiber laser; calibration-free method; particle swarm optimization

P26

Laser-Induced Plasma Acoustics and Laser-Induced Breakdown Spectroscopy: A Happy Marriage

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The relevance of laser-induced plasmas acoustics (LIPAc) investigations has skyrocketed in recent times, raised by NASA´s mission Mars 2020 research with the Mars Microphone. While LIPAc signal had been succinctly studied and applied, preferably, as a normalization asset to alleviate the shot-to-shot instability of the LIBS signal, knowledge about the structure and the components of the acoustic response, the effect that different parameters may had on it, as well as its behaviour in different scenarios, were yet unknowns on the background of the phenomenon.

Research herein focused first on the progress know-how of the LIPAc signal. The conditioning of sample-associated traits, instrumental variables, operational conditions, as well as the target-surroundings on the ensuing acoustic response has been evaluated. Even experiments inside a thermal-vacuum chamber (TVC), a facility that allows mimic planetary environments, have allowed LIPAc signal performance under non-standard atmospheres.

From all this, applicability of LIPAC has been demonstrated. The close link that the acoustic response maintains with the physical properties of the sample has made it possible to exploit its use to differentiate specimens that showed a very high similarity in the optical response of their plasmas, to enhance the identification of subsets within a whole, and even to correct discrepancies between atomic and ionic information derived from the matrix effect.

In short, the results derived from all these studies go beyond a mere declaration of intentions, demonstrating that the acoustics derived from laser-produced plasmas is a valuable source of information not only acting on its own but also contributing as LIBS-LIPAc combination.

Keywords: Acoustics; LIBS; Laser-produced plasmas

P27

LIBS Analysis of Amorphous LLZO Films

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Laser-induced breakdown spectroscopy (LIBS) is superior to many other chemical analysis methods for detecting light elements, such as lithium, and for enabling high-throughput screening of large-area samples [1]. Here, we used LIBS to study thin films of amorphous lithium-lanthanum-zirconium-oxide that were fabricated by sputter deposition on 4” silicon substrates. Crystalline $Li_7La_3Zr_2O_{12}$ (LLZO), fabricated at 700-1000°C, is a promising material for solid-state batteries due to its high ionic conductivity and electrochemical stability. In contrast, amorphous LLZO exhibits lower ionic conductivity but can be made at room temperature, simplifying the fabrication of a full battery cell. However, the ionic conductivity of amorphous films can be tuned by i.e. varying the Li content and deposition temperature [2,3], making accurate quantification of Li content critical for understanding the relationship between composition and performance.

Analyzing thin films using LIBS is destructive in the sense that the laser ablation can fully remove the sputtered layer. Furthermore, the lack of an internal matrix reference and the large number of emission lines complicates the interpretation of LLZO spectra. Here we investigate two approaches to LIBS analysis of thin LLZO films deposited on silicon substrates; 1) a laser-induced pre-melting of the film with the substrate, using the fundamental Nd:YAG laser wavelength, where the thin film is partially transparent, and 2) the use of a thin sacrificial metal layer deposited on top of the LLZO film prior to analysis. We will discuss the pros and cons of these methods for LIBS thin-film analysis, as well as issues related to LIBS analysis of lithium in general.

Keywords: Thin films; lithium; LLZO; laser fusion

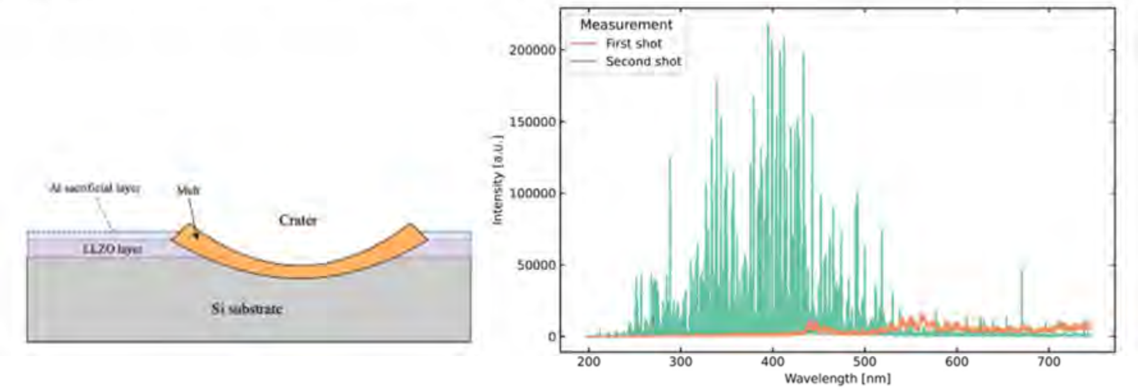

Fig. 1. Left: Schematic illustration of thin-film sample. Right: Emission spectra of first laser shot (melting) and second laser shot (plasma generation and atomic emission).

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P28

Multimodal Analysis of MALDI-MS and LIBS: Comparative Study of UV-355 nm and IR-1064 nm Desorption.

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Most MALDI spectrometers use UV lasers for desorption. However infrared light is an interesting alternative [1], in particular because it involves different modes of light-matter interactions. For example, the 2.9 µm wavelength matches to the O-H vibrations ubiquitous in biomolecules, which allows alternative choices for the matrix, e.g. glycerol or frozen water[2]. Nd:YAG lasers, emitting at 1064 nm, also represent an attractive light source.

In order to compare the MALDI MS spectra obtained with light sources at 355 nm and 1064 nm, we used a commercial MALDI MS spectrometer (UltrafleXtreme, Bruker) modified to allow both measurements on the same platform. In addition, our MALDI device was coupled with an optical spectrometer to analyse, in real time, the light emitted during the desorption process. This configuration allows LIBS (Laser-Induced Breakdown Spectroscopy) techniques to be applied directly to the impacted area, paving the way for innovative multimodal analyses.

We studied different model molecules of different types : peptides, polymers and proteins. Different matrices were also used, including graphite, α-cyano-4-hydroxycinnamic acid (HCCA) and sinapic acid (SA) combined with different salts such as KI, $CaCO_3$ and NaI.

Our preliminary results demonstrate that it is possible to detect characteristic atomic and ionic emissions during desorption, illustrating the value of MALDI-MS-LIBS coupling for better understanding the underlying mechanisms of ablation and ionisation. This approach combines the advantages of molecular mass spectrometry and elemental analysis, offering new perspectives for the in-depth study of surfaces and material-laser interactions, as well as for the development of integrated analytical protocols.

Keywords: MALDI-MS-LIBS coupling; multimodal analysis

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P29

Plasma-atmosphere interactions in Martian LIBS and implications for carbonate characterization

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Three LIBS instruments have successfully been deployed on Mars so far: ChemCam onboard NASA's Curiosity rover (2012-ongoing) [1-2], SuperCam onboard NASA's Perseverance rover (2021-ongoing) [3-4], MarsCode onboard the Chinese Zhurong rover (2021-2022) [5], providing chemical information for thousands of targets on three areas around Mars. One challenge with LIBS on Mars is to characterize the carbon-content of a sample, since the Martian atmosphere (~6 mbar of CO_2) contributes some C and O signal in all LIBS spectra [6-11]. We aim to characterize the plasmaatmosphere interactions and **atmospheric contribution to the carbon signal in Martian LIBS spectra**.

We use **temporally and spatially resolved plasma observations** to study the dynamics of carbon in the plasma depending on the origin of the carbon: either the sample or the atmosphere. Using the setup from DLR-WR-ISS, Berlin [12-13], we image the C I 248 nm, C II 251 nm, O I 777 nm and O II 689 nm emission lines. Measurements are performed in 6 mbar of Martian atmospheric simulant (96% CO_2) or 6 mbar of air (for comparable plasma development), on pellets of pure graphite, Mg-carbonate and Mg-sulfate, respectively.

We will show that the atmospheric C and O content contributes significantly to plasma's C I and I emissions, influencing the intensity of the investigated emission lines, as well as the spatial distribution of these species with the plume. In particular, C I from the sample appears to remain in the central region of the plasma, whereas atmospheric C I is located in a thick envelope farther out (Fig. 1). For the signals of C II and O II, which remain close to the plasma center in all configurations, the difference is mostly in signal lifetime.

We will discuss the implications of our findings for carbon characterization in geological targets on the surface of Mars.

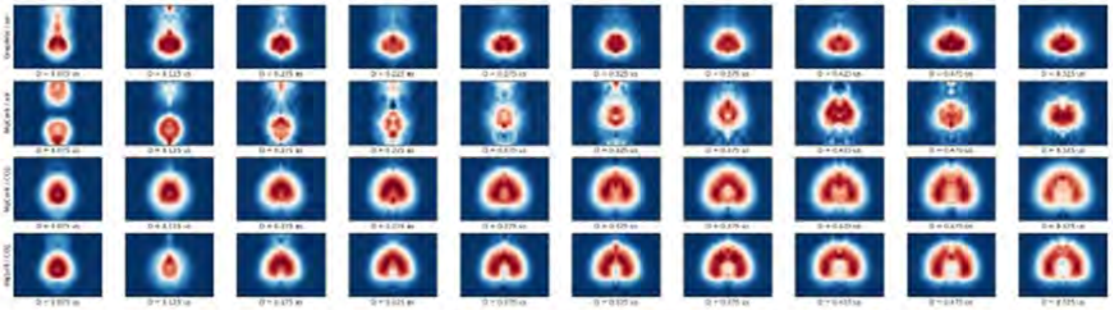

Fig. 1 Plasma imaging of C I 248 nm in 4 experimental configurations (P = 6-7 mbar): Graphite in air; Mgcarbonate in air; Mg-carbonate in CO2; Mg-sulfate in CO2. The acquisition gate is 50 ns and the delay increased in the time series with 50 ns steps; 10 shots are accumulated for each image. The images were cropped, stitched (2 heights), smoothed and Abel inverted, to correct for the integration of signal along the way of sight.

Keywords: Carbon; Atmosphere; Mars; Plasma imaging.

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P30

Sampling approaches based on spot aerosol generation, Catapulting and Trapping combined to LIBS

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Different strategies to handle samples and perfom LIBS analysis are described. Three approaches will be detailed that result extremelly helpful when dealing with heterogeneous samples that are intended to be analyzed by laser-induced breakdown spectroscopy (LIBS). The first one involves the spot aerosol generation (SAG), where an aerosol of nano/microparticles is created locally by a low-energy laser pulse. These particles can be directly analyzed in gas phase (straight LIBS) , being optically trapped for single-particle LIBS (Optical-Trapping LIBS, OT-LIBS) , or analyzed once collected in the substrate by optical catapulting followed by LIBS (Optical Catapulting LIBS, OC-LIBS). Additionally, acoustic trapping is being explored as a useful way to handle liquids or samples with size and density not compatible with optical traping.

The poster will summarize the different experimental configurations and applications developed with each approach in diverse areas that include space geochemistry (analysis of meteorites), environmental (nanoparticles) and industrial analysis (powdered raw materials in 3D metallic and polymer printers).

Keywords: LIBS; Sampling strategies; Optical trapping; Optical Catapulting; Acoustic Trapping; Aerosol generation

P31

Spatially Resolved LIBS Analysis of Nanoparticle Clouds Formed during Single Particle Iron Combustion

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Nanoparticle formation during thermochemical oxidation of iron microparticle represents a major challenge for the viability of metal-fuel energy storage cycles. Quantitative and spatially resolved measurements of the process of nanoparticle formation are still lacking, limiting model validation and process optimization. In this study, a spatially resolved laser-induced breakdown spectroscopy (LIBS) approach for the in-situ analysis of nanoparticle clouds and the atomic surface composition generated by single laser ignited iron particles was developed. The particles were levitated in an electrodynamic levitator, subsequently ignited by an IR-Laser which promotes nanoparticle formation and then analyzed using LIBS. Simultaneous diffuse backlight illumination (DBI) high-speed imaging of the ignited particle was performed to visualize melting, nanoparticle formation and the plasma formation caused by the LIBS measurement. The method provides new insight into the local Fe, O and N atomic fractions inside of the nanoparticle cloud, surrounding gas phase and the particle surface. At the same time the developed method offers potential to be transferred as a measurement technique for spray-flame nanoparticle synthesis.

Keywords: nanoparticle formation; single-particle diagnostic; iron combustion; ps-LIBS; diffuse backlight illumination; spectral fitting; CF-LIBS

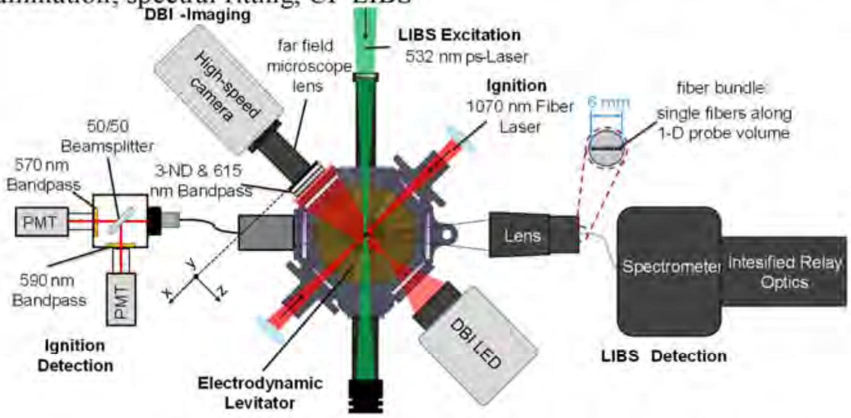

Fig. 1 Experimental setup with four subsystems: 1. Electrodynamic Levitator, 2. Particle Ignition and Detection, 3. LIBS-Excitation and Detection and 4. DBI Imaging.

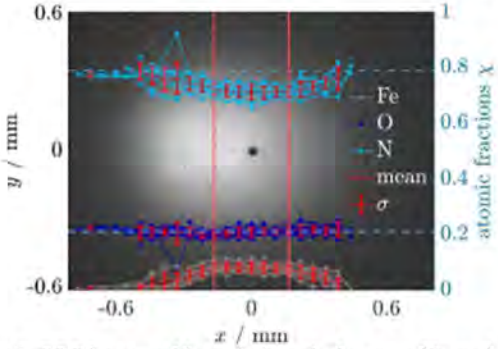

Fig. 2 Representative Grayscale DBI image of laser induced plasma of laser ignited iron particle and spatial distribution of atomic fraction for Fe, O and N along the centerline of the plasma from multiple measurements.

P32

Stand-off Spectroscopies Under Controlled Atmospheric and Temperature Planetary Conditions Using a Multipurpose Thermal Vacuum Chamber

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The availability of thermal vacuum chambers (TVAC) represents a need in today´s planetary research. A TVAC must be capable of operate under representative conditions (temperature, gas composition, pressure, radiation flux …) of space exploration targets but also have a useful volume compatible with the performing experiments and the testing of equipment under mimicked scenarios.

This abstract detail the TVAC designed and installed at UMALASERLAB to serve the astrochemical community. With a length of 12 meters and a useful internal diameter of 1.6 meters, the chamber operates in a temperature range between 200 K - 400 K and can be oil-free pumped down from atmospheric pressure to 10^{-4} mbar in the current configuration. Additional upgrades may extend the pressure range up to the 10^{-6} mbar range. Such figures and dimensions turn the TVAC of UMALASERLAB a powerful and versatile tool for space-related studies in chemistry, biology and engineering. The internal surface of the TVAC is black painted with a special enamel to improve the thermal emission of the surface itself and maximize light absorption (> 95 % at any angle) to reduce flares and ghost effects in the recorded spectra. For experiments demanding deep UV illumination, a high-power Xe lamp provides illumination conditions similar to those at Mars surface in the UV-A, UV-B and UV-C spectral regions over a diameter of 50 cm in the geometrical center of the TVC. A graphic user interface allows local and remote visualization, control and data logging of the vacuum pumps, the cooling/heating system, the pressure gauges, the thermocouple gauges, and the mass flow controllers for gas mix load in the chamber.

Different experiments performed inside the TVAC will be described including laser-induced breakdown spectrometry (LIBS), laser-induced plasma acoustic (LIPAC) and thermal imaging monitoring.

Keywords: Planetary spectroscopy; Stand-off spectroscopies; Thermal Vacuum Chamber

P33

Unveiling LIBS Analysis Insights: Exploring Plasma Confinement Induced by Variable Electric Fields in Both Ambient and Vacuum Environmental Conditions

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Abstract:

The study investigated the effects of applying an electric field to the plasma plume generated during Laser-Induced Breakdown Spectroscopy (LIBS) experiments on copper, aluminum and brass samples. The primary goal was to enhance the time-resolved analytical performance and improve the limit of detection (LOD) of the LIBS technique by employing high-voltage electric fields. Despite the theoretical potential for increased sensitivity and detection capabilities, the experimental results did not demonstrate the expected enhancements. The application of electric fields did not lead to significant improvements in the sensitivity or limit of detection for identifying trace elements in the samples. This outcome suggests that while the concept of electric field-assisted LIBS holds promise, further research is needed to fully understand and optimize the effectiveness of this approach in practical applications. Additional investigation is required to determine the factors that limit the anticipated performance gains and to explore strategies for realizing the theoretical benefits of electric field-assisted LIBS.

Keywords: LIBS, brass, Electric field, trace elements

P34

Perseverance/SuperCam LIBS technique: how to decide if a spectrum is of good quality?

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The SuperCam instrument [1,2], onboard the Perseverance rover, has been exploring Jezero Crater since February 2021. Over 1,000 individual martian targets have been analyzed using the SuperCam LIBS technique, corresponding to more than 320,000 individual spectra.

To assess the chemical composition of these targets, several models have been implemented. These models were developed using a database of LIBS spectra acquired on Earth, from well-characterized samples [3]. These models perform well and have shown to be consistent with findings from the other techniques from SuperCam (VISIR and Raman), and also from the PIXL instrument [4], even though some refinements are in progress [5]. However, these models have been built using data of good quality (good focus), which is not always the case for a spectrum acquired on Mars, due to poor coupling. This poor coupling can be due to the distance of the target (the farthest was 15 m away from the instrument), suboptimal focus, or rock textures and physical properties.

Therefore, it is necessary to control the quality of the martian data before matching them with the models This is essential to obtain an accurate estimate of the target's chemistry.
Several techniques have been developed to assess the quality of the spectra. First, the "LIBS Quality Index" [6], developed for the MarsCoDe instrument [7], and validated using ChemCam [8,9] spectra. This technique calculates how different the spectrum is compared to the spectra used in the database. Nevertheless, it has some bias, for example this index can be altered when a target is enriched in Ti.

Another technique is being developed, by using both the Signal-to-Noise Ratio (SNR) and the total emission of the spectra. The combination of these two criteria, along with the LQI, seems to be a good method to evaluate if a spectrum is of sufficient quality to be used for the chemistry assessment. In this presentation both methods will be presented along with the first assessments for the Mars data.

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P35

LIBS-Based Classification of End-of-Life Membrane Electrode Assemblies for Automated Sorting

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Efficient recycling of end-of-life (EoL) components enriched with critical raw materials, such as platinum group metals (PGMs), is crucial to recover valuable elements and reduce dependence on primary sources. Complex and heterogeneous materials containing these elements, like Membrane Electrode Assemblies (MEAs), present challenges for sorting due to their variable composition and the lack of standardized reference samples. In this context, Laser-Induced Breakdown Spectroscopy (LIBS) provides a rapid method to analyse and classify these components, facilitating the selection of the appropriate recycling route.

Within the framework of the CRUSADE project [1], LIBS is being applied as a complementary tool for the identification of three different classes of MEAs through the detection of multiple emission lines, including elements as Pt, Ir, Co, Ni or P. Specific measurement protocols were developed to address the challenge in sorting due to the compositional variability of MEAs. Preliminary results on classification show the potential of LIBS as a valuable technique for automated recycling and the recovery of critical raw materials.

Keywords: PGMs, MEA, EoL classification, critical raw materials.

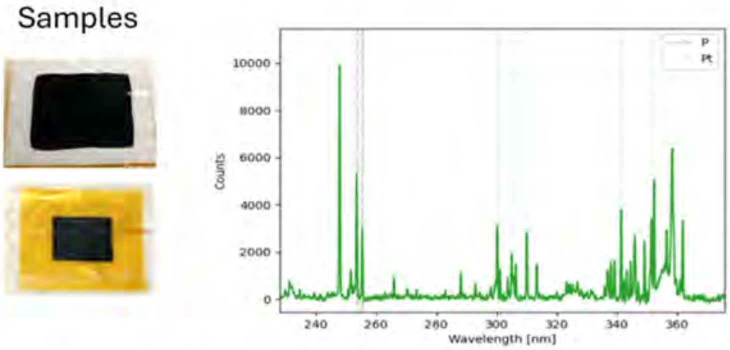

Fig. 1 End of life MEAs samples (left). Spectrum of PBI membrane with some P and Pt lines identified (right).

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P36

Molecular Features in LIBS of Refractory Materials

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This presentation will discuss the appearance of molecular features in the emission spectra of refractory materials, as well as simple relationships between the concentration of principal elemental components and feature height/area. Used, characterized and cleaned building materials are amongst the next targets, after metals, to be examined for use of LIBS in analysis, identification and separation. With the rapidly evolving refractories recycling sector, in part due to the presence of LIBS analysis, it will soon become the 'new normal' for refractory mineral purchasers to be offered a menu of their mineral requirements which will comprise two distinct and competitive refractory mineral sourcing options: primary and secondary raw materials. In spite of declining specific refractory consumption, around 35m tons per annum of refractory raw materials are consumed to make refractories worldwide. Problems related to raw refractory availability include limited development of commercial scale resources, overreliance on leading sources which have local issues impacting supply inconsistent quality and supply availability, pricing and logistics issues. Such factors are a nightmare for refractory raw material purchasers. Refractory mineral purchasers are therefore seeking alternative raw material sources, and in many cases will accept adequately understood recovered material streams. LIBS is, of course, as obvious candidate for refractory characterization because of its ability to probe both light and heavy elements. Automated material handling systems will ultimately need to handle larger and possibly more heterogeneous pieces than metal recycling systems. It is possible that surface preparation will be required to determine bulk composition rather than superficial "skin" analysis. We will present recent work on characterized refractory materials, including the appearance of molecular features in the visible region of certain types of samples.

Keywords: refractories, molecular, atomic, recycling

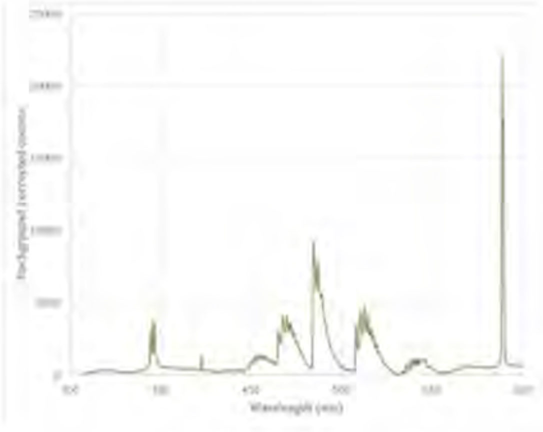

Figure 1. LIBS spectrum of high Al_2O_3 refractory material.

P37

Indirect determination of scaling anions in synthetic saline waters based on barium salt precipitation

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The deposition of inorganic salts in pipelines for oil exploration in marine platforms is one of the main causes of productivity decrease of the oil industry. The scales are formed by sulfates and carbonates of alkaline-earth metal ions, therefore making important the monitoring of these ions in waters in order to evaluate their scaling potential [1]. The purpose of the present work is the indirect determination of carbonate (CO_3^{2-}) and sulfate ions (SO_4^{2-}) by their precipitation as barium salts. For total CO_3^{2-} determination, a CO_2 absorbing system was developed (Figure 1a) and operated as follows: 1.2 mL of HCl solution (2.0 mol L^{-1}) was injected into the CO_3^{2-} sample, generating CO_2, which was carried by $N_{2(g)}$ to a NaOH solution (1.0 mol L^{-1}, 10 mL), where it was reconverted into CO_3^{2-}. Then, 2 mL of Ba^{2+} (9.0 g L^{-1}, 2 mL) were added to precipitate $BaCO_3$. For SO_4^{2-} determination, a 10 mL of SO_4^{2-} sample solution was mixed with 1 mL of HCl (4.0 mol^{-1}) to remove CO_3^{2-} interference. Then, 2 mL of Ba^{2+} were added to precipitate $BaSO_4$ (Figure 1b). In both methods, the suspension formed was filtered and an aliquot of 300 µL of the solution was dropped onto a 2.5-cm diameter quantitative filter paper disc, which was placed in an oven at 60 ºC for 1 hour. The excess of Ba^{2+} ions of the solution was determined, allowing the indirect determination of CO_3^{2-} and SO_4^{2-}. A Q-switched Nd:YAG laser (Brilliant Quantel B) was employed for LIBS measurements (1064 nm, 20 Hz, 5 ns, 90 mJ), using gate delay and gate width of 1.0 µs. Signal acquisition was performed by an echelle polychromator and an iCCD detector (iStar DH 734, Andor Technology). The methods were applied to different synthetic saline waters containing NaCl (0 - 7.0 g L^{-1}), total CO_3^{2-} (300 - 2972 mg L^{-1}) and SO_4^{2-} (150 - 1171 mg L^{-1}). For CO_3^{2-} determination, a calibration curve with a R^2 greater than 0.99 was obtained, with relative error ranging from -10 to +10% for the determination of the analyte in aqueous samples. Similarly, for SO_4^{2-}, the calibration curve also showed an R^2 higher than 0.99, with relative errors between -11 and +18%. The developed analytical methods, combined with LIBS measurement, shows potential for monitoring CO_3^{2-} and SO_4^{2-} in saline waters produced in oil marine platforms. (Petrobras 0050.0124645.23.9).

Keywords: Saline water; scaling ions; indirect determination; barium precipitation.

Fig. 1 (a) CO_2 absorption system for CO_3^{2-} determination and (b) analytical method for SO_4^{2-} determination.

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P38

LIBS of aqueous solutions: Quantification of $ZnSO_4$ transferred to paper matrix

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The concentration of zinc sulfate in aqueous solution was measured by double-pulse (DP) laser-induced breakdown spectroscopy (LIBS). $ZnSO_4$ is an essential chemical in the spin bath liquid used for industrial production of viscose fibers from cellulose. For DP-LIBS the $ZnSO_4$ analyte was transferred from the water matrix to a solid cellulose matrix (commercial filtration paper). Various emission lines of Zn in the UV/VIS range were measured at 560 different positions on the dried paper sample. The line intensities were strongly varying across the sample as observed by LIBS imaging (Figure 1).

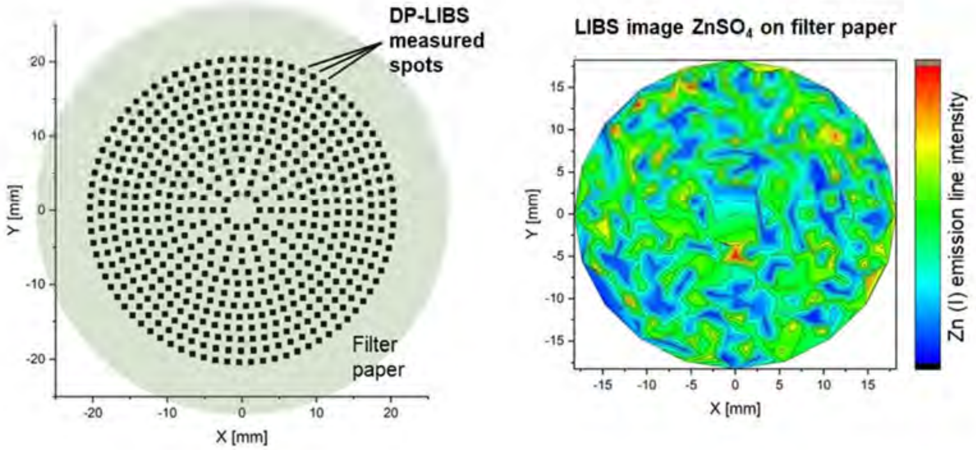

Fig. 1: DP-LIBS of $ZnSO_4$ on filtration paper (left). LIBS chemical image of Zn I at 334.5 nm (right).

Signal analysis revealed broad and bimodal distributions of line intensities. Normalization of the analyte intensities to emission line intensities of matrix elements reduced the apparent inhomogeneity of samples and achieved monomodal signal histograms and good analytical figures of merit. The mean error of predicted concentration of $ZnSO_4$ in aqueous solutions was RMSEP = 0.19 g/L for samples covering the concentration range C_{ZnSO4} = 0-11 g/L [1]. Applications of DP-LIBS in viscose fiber production can be envisaged.

Keywords: Laser-induced breakdown spectroscopy (LIBS); Liquid-solid matrix conversion; Zinc sulfate; Filtration paper; Cellulose.

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P39

Laser-Induced Breakdown Spectroscopy for Elemental Mapping and Tumor Detection in Oral-Jaw Tissue

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Identifying tumor margins in oral and maxillofacial surgery is challenging due to the heterogeneous composition of bone and surrounding soft tissue. In this ongoing study, we explore the potential of laser-induced breakdown spectroscopy (LIBS) as a fast, label-free technique for analyzing elemental variations in oral-jaw tumor samples.

2D scanning LIBS data were acquired from ex-vivo specimens containing both mineralized and soft tissue regions. The analysis focuses on the emission lines of calcium (Ca), sodium (Na), and potassium (K), which indicate differences in tissue composition. Elemental maps were reconstructed to visualize spatial distributions and to identify possible contrasts between healthy tissue and suspected tumor regions. Preliminary results show visible differences in Ca/Na/K intensity ratios, suggesting compositional changes that correlate with pathological alterations.

Ongoing work focuses on improving ROI-based analysis and baseline correction to increase reproducibility and spatial accuracy in predicting pathological tissue classification. The study demonstrates the potential of LIBS for providing complementary elemental information in fast tissue characterization and its potential future application in intraoperative tissue differentiation and surgical guidance.

Keywords: Tumor tissue characterization; calcium; sodium; potassium

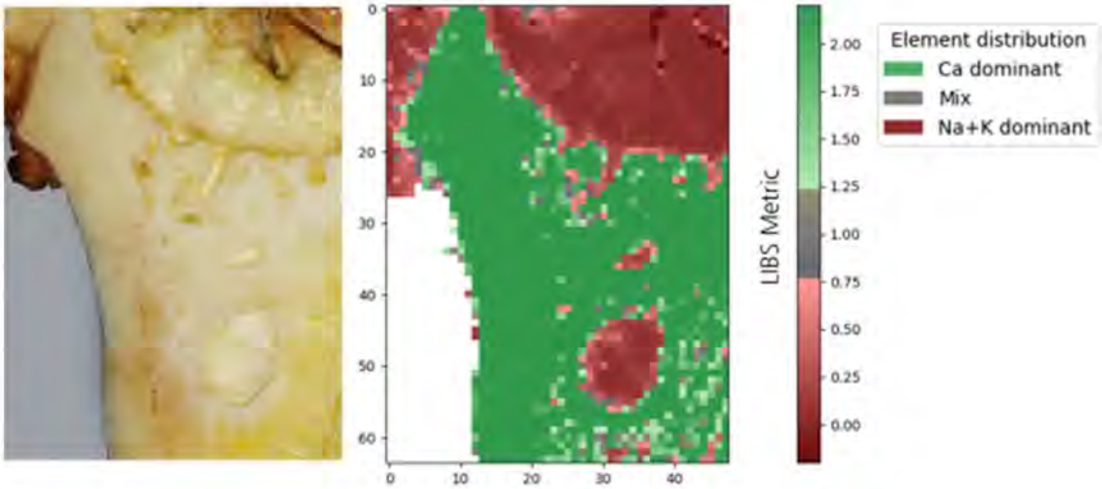

Fig. 1 Image of an oral-jaw tissue sample and its corresponding map of a LIBS metric derived from locally acquired single-pulse spectra. The image size is 48 x 64 spots, corresponding to 12 x 16 mm²

P40

Modeling of Laser-Induced Heat Conduction Dynamics in Aluminum under Nanosecond Pulse Excitation

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Understanding heat transfer mechanisms under extreme temperature conditions is crucial for nuclear materials, where direct experimental reproduction is challenging. Laser–matter interaction offers a versatile approach to simulate such environments. This study presents a one-dimensional theoretical simulation of heat conduction in aluminum subjected to nanosecond Nd:YAG laser irradiation, employing a finite-difference scheme to capture the transient thermal response. The 1-D heat conduction equation was solved [1] under temperature-dependent boundary conditions to estimate surface temperature, ablation depth, and plasma velocity as functions of laser fluence.
A Gaussian laser pulse of 5 ns width was modeled, and the substrate was discretized into fine spatial grids. Temperature at each node was iteratively updated, and when it exceeded critical thresholds, phase transitions such as melting, homogeneous and heterogeneous boiling, and explosive boiling were incorporated. Thermo-physical properties were dynamically updated with temperature to accurately represent the phase-change behavior. An in-house developed code based on Fortran algorithm ensured numerical stability and efficiency during rapid transients. Results reveal the evolution of temperature profiles with both spatial and temporal resolution, delineating heat-affected and ablated zones. The temporal evaluation is presented in Fig. 1. Plasma shielding effects were also modeled, demonstrating that plume formation attenuates incident energy, thereby influencing surface heating and material removal dynamics. The analysis of plasma velocity and temperature provided further insight into plume expansion and energy redistribution.

The proposed framework unifies heat conduction, plasma shielding, and phase-transition dynamics into a single computational model that captures the complex, nonlinear behavior of materials under intense laser irradiation. Its capability to reproduce extreme heating— that can be to a extend comparable to that encountered in reactor environments—extends its significance well beyond conventional laser processing. This powerful simulation tool thus establishes a robust predictive platform for exploring and understanding high-temperature phenomena and material evolution in demanding nuclear and industrial conditions.

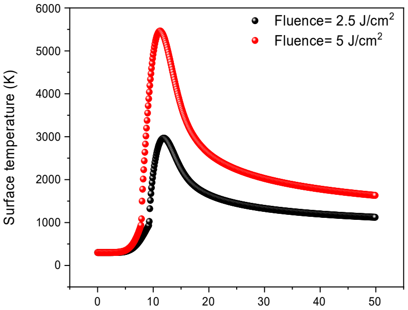

Fig. 1. Temporal evolution of surface temperature in different fluence conditions

Keywords: Heat conduction, Laser Induced Plasma, Aluminium

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P41

Application of Eye-Safe LIBS for Uranium Identification and Spatial Distribution Studies in Geological and Engineering Materials

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Uranium occurs in a wide range of geochemical forms within rocks, either as distinct uranium-bearing minerals or as an isomorphic component incorporated into the crystal structures of other minerals. It can thus enter the environment through natural processes, for instance by weathering and leaching of primary uranium minerals such as uraninite or their secondary alteration products. In addition, anthropogenic activities, particularly those associated with uranium ore processing, can also contribute to its release. Although uranium mining activities in Europe are currently limited, several regions remain rich in uranium deposits, and local contamination originating from former mining and ore treatment activities is still present.

Identifying and characterizing the presence of uranium in geological structures is essential not only for geological exploration but also for assessing potential migration pathways. Due to its relatively high solubility in aqueous environments, uranium can easily mobilize into groundwater and surface water systems, thus posing both environmental and health-related concerns.

For this reason, it is not sufficient to determine only the total concentration of uranium in bulk samples; equally important is the mapping of uranium distribution at the micro- to millimeter scale. Spatially resolved analyses make it possible to evaluate how uranium is incorporated in mineral phases, how it is bound to surfaces of engineered materials such as metals, or how it interacts with bentonite, which is considered a key component of engineered barriers in radioactive waste repositories. At the same time, it allows the identification of local potential uranium contamination.

Laser-Induced Breakdown Spectroscopy (LIBS) represents a rapid, robust, and efficient method for detecting uranium in minerals and other geological matrices. It can be applied both in situ and under controlled laboratory conditions. However, direct in situ use in inhabited or publicly accessible areas is challenging because of potential safety hazards, such as the risk of ocular damage from scattered laser radiation. To address this issue, our work tested the application of LIBS using lasers operating in the eye-safe spectral range, specifically at emission wavelengths of 1.54 µm (Er:Glass), 1.64 µm (Er:YAG), 2.01 µm (Tm:YAG), and 2.12 µm (Ho:YAG), with additional experiments performed using a 1.34 µm microchip laser. The results obtained were compared with conventional LIBS measurements using the 1.06 µm Nd:YAG laser.

The results of this research therefore have significant practical implications for safe and efficient uranium detection in a variety of geological and environmental contexts. Applications include rapid screening of uranium-rich areas and preliminary evaluation. Ultimately, the combination of LIBS detection with spatial mapping approaches contributes to a better understanding of uranium distribution and behavior, while also minimizing associated health and environmental risks.

Keywords: Uranium; LIBS; Mapping

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P42

Application of Laser-Induced Breakdown Spectroscopy (LIBS) for Rapid Detection and Determination of Mycotoxins in Food Matrices

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Mycotoxins, toxic secondary metabolites produced by fungi such as *Aspergillus*, *Fusarium*, and *Penicillium*, pose a serious threat to food safety and public health due to their widespread presence in cereals, nuts, and other agricultural products. Current methods for mycotoxin detection—such as HPLC, LC-MS/MS, and ELISA—are accurate but often require extensive sample preparation, expensive reagents, and time-consuming protocols **[1]**. As food safety regulations become increasingly stringent, there is a growing need for rapid, cost-effective, and non-destructive analytical techniques for routine mycotoxin screening.

In this study, we explore the feasibility and performance of Laser-Induced Breakdown Spectroscopy (LIBS) as a novel approach for the detection and characterization of mycotoxincontaminated food samples. LIBS operates by focusing a high-energy laser pulse on the sample surface, generating a microplasma whose emission spectrum provides a unique elemental fingerprint.

Although LIBS is traditionally used for elemental analysis, the use of chemometric tools **[2]** may also capture molecular signatures indirectly associated with mycotoxin presence, especially when combined with chemometric tools.

Multiple food samples artificially contaminated were analysed with known concentrations of zearalenone. Spectral data were processed using Principal Component Analysis (PCA) to discriminate between contaminated and non-contaminated samples, and to quantify toxin levels. These results demonstrate that LIBS, coupled with multivariate analysis, can effectively differentiate contamination levels within the same range as conventional methods.

The findings suggest that LIBS offers a promising alternative for rapid on-site screening of mycotoxins, particularly in quality control processes in the food industry. Its minimal sample preparation portability, and real-time feedback capabilities make it highly suitable for field applications. Further work will focus on improving sensitivity, expanding the range of detectable mycotoxins, and developing portable LIBS devices tailored for agro-food environments.

Keywords: Mycotoxins, LIBS, food safety, rapid detection.

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P43

Assessing Metal Contamination in Horticultural Substrates: A Dual-Pulse LIBS Approach

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Heavy metals pose significant environmental and health risks due to their persistence, bioaccumulation, and toxicity. Rapid and reliable detection methods are essential for monitoring contamination in soils and substrates. This study explores the application of dual-pulse LIBS for the screening of heavy metals in horticultural substrates, with emphasis on standardized ISO garden soils. LIBS offers a sensitive, non-destructive, and real-time analytical approach capable of detecting trace metal concentrations without extensive sample preparation. The method's potential is discussed in the context of environmental monitoring and soil health assessment, particularly in areas affected by industrial pollution and ecological burdens.

In this study, a geometrically configured dual-pulse LIBS approach was applied to improve the detection of target metals (e.g. Cu, Pb, Zn or Cr) in substrates. A single laser beam was divided into two parts intersecting at a 50° angle at the sample surface, resulting in enhanced plasma formation and stronger emission signals compared to the conventional single-pulse mode. This purely geometric dualpulse configuration enables efficient energy coupling into the ablation zone without the need for complex synchronization or timing control. The method combines minimal sample preparation with real-time analysis, making it highly suitable for environmental monitoring and assessment of soil health in contaminated or industrially impacted areas.

Keywords: Heavy metals; LIBS; Horticultural Substrates

ACKNOWLEDGEMENTS

This research was funded by the Technology Agency of the Czech Republic under project No. SQ01010267, aimed at "Determining the concentration of heavy metals in environmental samples for the assessment and characterization of ecological burdens." We would also like to express our gratitude to the Faculty of Nuclear Sciences and Physical Engineering, Department of Nuclear chemistry for the support.

P44

Development of a miniaturised Laser induced Breakdown Spectroscopy apparatus for in-situ analysis of effluents

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In the United Kingdom, the Nuclear Decommissioning Authority, through Sellafield Ltd, is currently engaged in a program to remove radioactive waste from its legacy storage ponds on the Sellafield nuclear site and elsewhere. Characterisation of a nuclear site is a fundamental step to assess physical, chemical, radiological and biological properties to support informed decisions about the site decommissioning. Typically, this would occur via collection of solid and liquid samples followed by laboratory analysis.

However, this is both challenging (from both a logistical and safety point of view) and costly. Remote, in-situ analysis may offer a safer, faster and cheaper option, whilst also providing an opportunity to undertake more frequent analysis of the presence of radionuclides in the waste and the concrete of the walls of the ponds.

This work is aimed at exploring the characterisation of both liquids and submerged samples, ideally remotely and with no sample preparation, using laser-induced breakdown spectroscopy (LIBS).

There has been initial work on measurements of solutions containing elements of interest (magnesium, strontium, cobalt and aluminium) and preliminary measurements of corroded Magnox sludge (CMS) using a benchtop LIBS system (Applied Photonics ltd. LIBScan 150). The current focus of the work has been on the development of a prototype system using a miniature ‘matchbox’ laser (integrated optics pulsed 1030 nm matchbox Laser) and a variety of optical focusing assemblies in order to test the viability of using this laser for a deployable probe. The preliminary results have shown that a measurement can be taken on the surface of a liquid using an instrument of a small enough size to deploy in-situ, however these measurements are of a lower quality than benchtop instruments. Future works will focus on improving these results through better optimisation of the optics.

P45

Laser-Based Phytomining: Real-Time Monitoring of Trace-Element Enrichment in Sweet Lupines Using LIBS

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Global estimates show that over half of the world's population lacks essential micronutrients [1]. In the project *LuPhytSpE*, we enrich sweet lupines (*Lupinus angustifolius*) with trace elements (Zn, Fe, Se) through agronomic biofortification and monitor the uptake and enrichment dynamics of these microelements using laser-induced breakdown spectroscopy (LIBS) — a fast, multi-element, and minimally invasive technique. Unlike ICP-MS or AAS, LIBS requires no chemical digestion and enables real-time, *in-situ* analysis of plant tissue, making it ideal for tracking elemental changes along the growth cycle and locating enrichment hot spots in the plant [2,3]. Within this framework, we optimize LIBS preprocessing and calibration strategies to reduce matrix effects and enhance trace-level detection in biological materials.

To address strong matrix dependencies in plant-based LIBS, we combine controlled pyrolysis preprocessing to stabilize volatile organic matrices and reduce water-induced spectral variation with spectral and physical characterization of trace element lines in lupine and related plant tissues. In parallel, calibration, spiking, and signal correction strategies are developed to improve accuracy in complex biological substrates. Measurements are performed on pressed pellets of plant material with varying water content, spiked samples with defined trace-element additions, and across different plant parts (stems, leaves, seeds) to identify element-specific enrichment patterns and localization within the plant. Additional investigations include element mapping in micro-compartments using LIBS microscopy, calibration models based on various machine learning regression methods, and the characterization of different enrichment strategies to evaluate their efficiency and reproducibility.

Our results show that targeted pyrolysis enhances signal stability for trace-level detection and reduces matrix effects without chemical digestion. Comparative analyses highlight the strengths and limitations of different enrichment and calibration approaches, while LIBS microscopy reveals distinct element distribution patterns across plant parts. Together, these findings lay the groundwork for a portable LIBS platform for in-field monitoring of trace elements within the *LuPhytSpE* framework—linking sustainable plant production with real-time nutrient diagnostics.

Keywords: phytomining; agriculture; micronutrient enrichment; biofortification

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P46

Deuterium limit of detection estimation in 316L by picosecond LIBS and MERLIN calculation

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Estimating the limit of detection (LOD) of deuterium in SS316L is a crucial step toward determining its limit of quantification (LOQ), enabling Laser-Induced Breakdown Spectroscopy (LIBS) for tritium depth profiling in Eurofer97. Deuterium serves as a non-radioactive analogue of tritium, while SS316L acts as a spectroscopic surrogate for Eurofer97 due to their similar Fe–Cr composition. LOD estimation combines picosecond-LIBS measurements with synthetic spectra generated using the MERLIN code [1], which reconstructs spectra under local thermodynamic equilibrium (LTE) for Calibration-Free LIBS (CF-LIBS) analysis.

LIBS measurements were performed using an infrared picosecond laser in argon, with plasma emission analyzed via a Czerny-Turner spectrometer and emI-CCD camera. Plasma parameters from calibrated spectra were used to generate MERLIN synthetic spectra. The electron density, obtained from Stark broadening of Ar lines, was determined to be $(4.0 \pm 0.8) \times 10^{22}\ m^{-3}$. The temperature, derived from Saha-Boltzmann plots of Fe and Cr, is $(8820 \pm 810)\ K$. The LTE condition is confirmed through the linearity of the data points relative to the regression fit. Using CF-LIBS, the Fe/Cr concentration ratio in 316L is measured as $(3.21 \pm\ 0.37)$, consistent with the standard 316L composition.

Figure 1 shows a good agreement between experimental spectra (in black dots) and MERLIN-simulated spectra (in blue line), obtained with 0.8% H (identified from H I line 656.28 nm) and 85.2% Ar in the plasma mixture. Some Cr lines show discrepancies, likely due to unknown Stark broadening and database differences. This composition is maintained constant while varying the deuterium molar fraction in SS316L. Progressive inclusion of deuterium in the MERLIN simulations (red line) indicates that a molar fraction of 0.7% D in 316L is sufficient to identify the D I line at 656.10 nm, which overlaps with the Cr I line at 656.11 nm and slightly higher spectral radiance than the H I line. The LOQ of D is expected to be above 0.7%. Complementary LIBS measurements employing controlled hydrogen gas injections, representative of the estimated deuterium contribution in the sample, will be presented to corroborate these results.

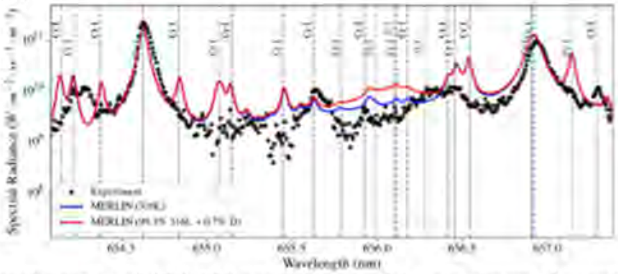

Fig. 1 Spectra of 316L in the range of 654-658 nm (in log-scale): experimental spectra (in black dot), MERLIN calculation of experimental condition (in blue line), and MERLIN calculation of deuterium estimation by 0.7 % in the sample (in red line)

Keywords: LIBS, deuterium detection, Eurofer97, fusion materials

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P47

Hydrogen isotope analysis in polymers by ns LIBS, fs LA-MS and μ-Raman spectroscopy

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The quantitative analysis of isotopes is an important topic in scientific and industrial research. Hydrogen isotopes, in particular, play a significant role in geo- and biochemical studies and in many other fields. In recent years there is also an uptick in fusion-related research, where hydrogen isotopes often are the fuel and/or the product of nuclear reactions [1]. Quantitative hydrogen isotope analysis in these applications require a.) reliable isotope calibration standards which can also be used in a vacuum environment, b.) fast and sensitive analytical methods with stand-off capabilities. Our approach to respond to these needs was to synthesize polymers using a mixture of monomers containing isotopically enriched variants and to use laser spectroscopy for the analysis. The advantage of using polymers as calibration standards is that they contain the hydrogen isotopes in a covalently bonded form, therefore they can not take part in isotope exchange with the humidity of air. If the polymer has a high molecular weight, it is also vacuum-stable. The laser spectroscopy methods we use for analysis are nanosecond laser-induced breakdown spectroscopy (ns LIBS), femtosecond laser ablation mass spectrometry (fs LA-MS) and micro Raman spectroscopy (□-Raman).

In this work, we synthesized various polymers and polymer blends, such as different acrylates and polystyrene, with controlled deuterium concentration. We studied the effect of several photoinitiators and sample preparation methods on the mechanical and laser ablation properties, as well as on the homogeneity of the polymer composition. Doping the polymers with gold nanorods was also tested, which is a requirement for laser targets to be used in the NAPLIFE (Nano-Plasmonic Laser Induced Fusion Energy) project that aims to use high-intensity lasers to ignite fusion on a small scale with the help of nanoplasmonic effects [2]. Our ns LIBS vacuum analytical system has 1064 and 532 nm laser wavelengths, therefore we also explored potential ways to mix in additives (e.g. dyes or solid particles) with the polymers in order to increase their light absorption at the laser wavelengths. Optimalization of the measurement parameters for all the three used laser spectroscopy methods was also performed, which allowed us to achieve good accuracy and precision in quantitative hydrogen isotope analytical measurements.

Keywords: polymer; hydrogen; plasmonics; fusion

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P48

2D Mapping of Peridotite Analogs as Target Minerals for Martian Missions using Planetary Exploration Technologies

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Peridotites represent ultramafic lithologies characterized by wide mineralogical and chemical variability making them ideal natural analogs for testing and validating analytical techniques relevant to planetary exploration. In this work, a peridotite sample from the Ronda Massif (Málaga, Spain) was characterized demonstrating a practical methodology for distinguishing geochemically distinct regions within complex lithologies [1]. The sample was analyzed using a multi-instrumental approach combining LIBS, micro-energy dispersive X-ray fluorescence (μ-EDXRF), and Raman spectroscopy, all of which are integrated into the Perseverance rover payload. LIBS and μ-EDXRF were used to assess elemental composition and spatial distribution across the sample, and the results of both techniques for major elements showed good agreement in spatial trends. However, LIBS was also able to identify minor elements such as C Sr, and Na, which are of particular interest in mineralogical studies due to their relevance in mineral structure, alteration processes, and geochemical signatures. Raman spectroscopy confirmed the presence of mineral phases such as olivine, pyroxenes, and chromiferous spinels in specific regions. Elemental LIBS ratios such as Mg# (Mg/(Mg+Fe)) and Cr# (Cr/(Cr+Al)) supported the identification of compositional variations related to mineral phases [2]. Spectral LIBS data were processed using k-means clustering to segment geochemical zones and detect spatial trends. This integrated spectroscopic and statistical approach enables a better interpretation of ultramafic rock complexity and provides an efficient framework for planetary exploration under mission constraints.

Keywords: Mapping, k-means, Martian Analog, geochemistry.

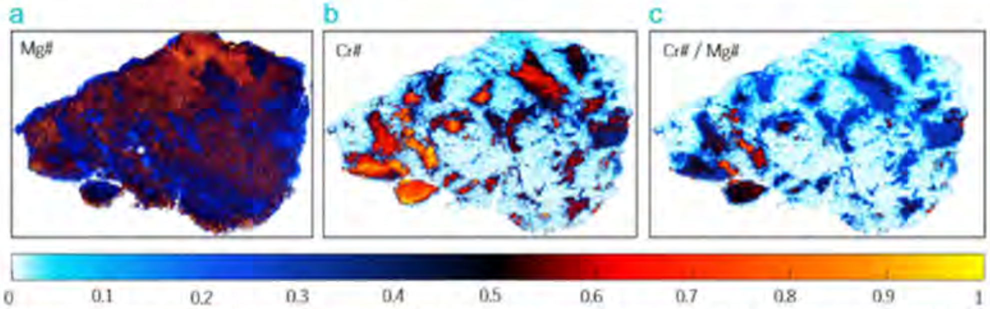

Fig. 1. Spatial distribution of intensity ratios of a) Mg relative to Fe or Mg#, b) Cr relative to Al or Cr#. c) Cr# /Mg# highlighting variations in chromium content relative to magnesium across the mapped region

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P49

Detection of Amorphous Carbon Enclosed in Hydrothermal Gypsum Deposits by Combined LIBS and Raman Spectroscopy: Implications for Biosignature Detection in Planetary Exploration

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The potential of laser-induced breakdown spectroscopy (LIBS) for detecting and characterizing carbonaceous materials in mineral matrices is attracting increasing interest in planetary exploration [1]. This work presents the first evidence of amorphous carbon enclosed within hydrothermal gypsum ($CaSO_4\cdot 2H_2O$) crystals from the Mina Rica mine (Pulpí, Almería, Spain), a recognized Martian analog site. The study integrates LIBS, Raman spectroscopy, and SEM-EDX to investigate the composition and distribution of carbon-bearing inclusions.

LIBS analyses revealed C(I) (247.8 nm) atomic and CN ($\Delta v = 0$) molecular emissions in both dark inclusions and siderite-free regions, indicating the presence of carbonaceous material trapped within gypsum cleavage planes. Depth profiling confirmed the shallow distribution of carbon, while spectral ratios were used to discriminate Fe emissions from siderite. Complementary Raman spectroscopy identified the broad D (1332 cm^{-1}) and G (1602 cm^{-1}) bands that are characteristic of amorphous carbon with a low degree of graphitization. On the other hand, SEM-EDX mapping shown micron-sized, carbon-rich particles dispersed within the gypsum matrix.

These findings demonstrate the capability of LIBS, especially when combined with Raman spectroscopy, to differentiate between organic and inorganic carbon sources in sulfate minerals. The results highlight the suitability of gypsum as a potential preservative host for biosignatures, reinforcing the applicability of LIBS for in situ astrobiological exploration on Mars and other planetary bodies.

Keywords: LIBS, Raman spectroscopy, gypsum, amorphous carbon, Martian analogs, biosignatures

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P50

Effect of Laser Spot Size and Granulometry on LIBS Plasma Parameters in Geological Samples

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Laser-induced breakdown spectroscopy has been proposed for studies of rocks and other geological samples. However, some applications, such as the analysis of extraterrestrial samples require calibration using laboratory-prepared pellets and laboratory studies may differ from in-situ applications in experimental parameters such as spot size. The aim of this work is to analyze variations in the characteristics of the ablation plasma as a function of sample particle size and ablation spot size in LIBS experiments performed on rock samples.

Different samples were obtained by milling various rocks and sieving them into particle range size from 2 to 0.037 mm. Samples were ablated under atmospheric using the fundamental wavelength of a nanosecond Nd:YAG laser, with an energy of 100 mJ. The focusing distance was varied to obtain a range of spot diameters ranging from 0.044 to 0.38 mm. Electron density and plasma temperature were determined from spectra acquired with both temporal resolution and time integration (see Fig. 1).

Preliminary results show that as the spot size increases, plasma parameters become dependent on particle size. Pellets made from smaller particles tend to exhibit higher temperatures and electron densities than those composed of larger particles or unprocessed rock samples.

Keywords: Plasma parameters; Rocks; Ablation spot; Matrix effect.

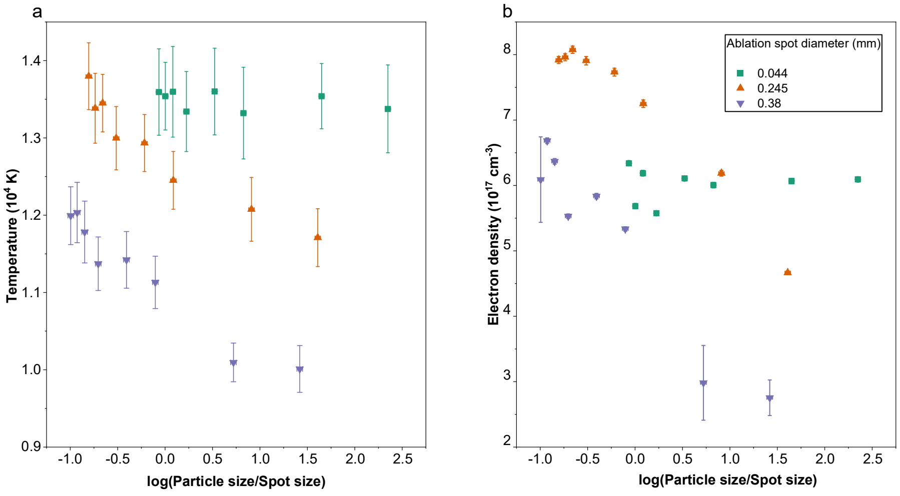

Fig. 1 Influence of the relationship between particle size and spot diameter on plasma parameters. Results obtained from selenite samples with a gate delay of 700 ns and a gate width of 100 ns. Three different ablation spots are shown, corresponding to different focusing distances.

P51

Fluorine Quantification in PFAS Compounds Using a Dual Experimental and Numerical LIBS Approach

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An increasing number of studies highlight the potential of LIBS (Laser-Induced Breakdown Spectroscopy) for pollutant detection across various environmental media. This analytical technique has been successfully applied to solids (e.g., soil contamination [1]), liquids (e.g., water pollution [2]), and gases or aerosols (e.g., air pollution [3]). In the present study, we focus on persistent pollutants known as PFAS (Per- and Polyfluoroalkyl Substances), which are commonly found in aqueous environments, particularly in rainwater [4]. These molecules are typically composed of carbon-fluorine bonds and one or more functional groups, which confer unique physicochemical properties and industrial relevance. The objective of this work is to quantify fluorine concentrations in environmental liquid samples using LIBS, originating from PFAS, or from another source of contamination. To this end, LIBS measurements are performed on aqueous solutions containing fluorinated molecules. Although this technique enables the detection and quantification of fluorine, its inherent limitations in providing molecular-level information render it unsuitable for comprehensive PFAS identification. Nevertheless, LIBS offers several advantages, notably its rapid analysis capability, low operational cost and suitability for in-situ measurements.

To address this limitation, numerical simulations are employed as a complementary approach. The modelling of laser-induced plasma formation and evolution is carried out using **YALES2** [5], a high-fidelity, multi-physics CFD code. As an initial step, simulations are conducted in a simplified argon (Ar) environment to establish a baseline and validate the numerical framework. This foundation will then be extended to more complex configurations, including air (N_2–O_2) and aqueous solutions containing PFAS compounds, with the objective of improving the interpretation of LIBS signals and enhancing molecular-level detection capabilities.

Keywords: fluorine; LIBS; numerical simulations; PFAS.

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P52

Laser-Induced Breakdown Spectroscopy as a Cutting-Edge Tool for Identifying Plastic Composition and Verifying its Sustainable Use in the Design Field

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This research analyzes the composition and identification of plastics using laser-induced breakdown spectroscopy (LIBS) to support their sustainable use in design. Design entails integrated decisionmaking about the formal, functional, and material qualities of products. As everything manufactured is first designed, this stage becomes crucial in shaping material reality. Unlike natural systems, designed systems follow guided processes that define their creation, use, and disposal; thus, designers share responsibility for material choices and their impacts on human and environmental health, including pollution from microplastics and nanoplastics. Currently, most design decisions rely on material catalogs or institutional libraries, focusing on the meso (material) level rather than elemental composition. However, contemporary ecological challenges demand micro-level information— specifically, data on the elemental makeup of materials—to enable responsible decision-making. Understanding material composition and traceability is essential for sustainable design and lifecycle management. Within the metasystem design framework, which emphasizes awareness of material flows and interconnected systems, this study contributes micro-scale data on the properties of the components of designed objects. Using LIBS, we demonstrate a rapid, non-destructive method for identifying and characterizing polymers, addressing current manufacturing needs and promoting accountable design amid plastics' widespread use, short life cycles, and lasting environmental and health impacts.

Keywords: Laser-Induced Breakdown Spectroscopy; Plastics characterization; Design; Sustainability.

P53

LIBS Implications in Planetary Exploration: The Search for Organic Biosignatures

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In the task of advancing in the ability to evaluate the potential presence of life on other planets, in this work we describe several studies that focus on establishing different strategies for organic biosignature identification. Terrestrial analogues are explored because of their potential as reference models to study and reproduce processes occurring in other planetary environments. Therefore, different materials associated with ancient biogenic processes have been selected for analysis by LIBS due to their potential to host and preserve organic matter, thereby serving as a proxy for the detection of past biosignatures. Oil shale rocks with kerogen content [1], moonmilk-type endokarstic speleothems with amorphous carbon content [2], and oncoid-type organosedimentary deposits were selected as analogue samples on Earth for the study [3]. Characterization of molecular emissions by LIBS and other auxiliary analytical techniques allowed clues to be obtained about biological activity. The results highlight the relevance of elemental techniques such as LIBS in the characterization of singular geological samples for astrobiology research.

Keywords: Mars analogues, LIBS, biosignatures, molecular emission

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P54

LIBS-Detection of Harmful Metals in Plant Material

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Natural circumstances, but also the extraction of raw materials, can lead to the accumulation of harmful elements in plants. For the further use of plant components as food or feed or as building materials, there are therefore limits that must be checked for compliance.

Our investigations focus on the contamination of plant material with copper, lead, and zinc. We have carried out LIBS measurements on contaminated plant material using various lasers with pulse lengths in the ns and fs range and with various spectrometers. Mapping techniques [1] allow us the spatially resolved determination of the contamination of plant material. The latest results will be presented.

Keywords: Plant Contamination; Nanosecond LIBS; Femtosecond LIBS.

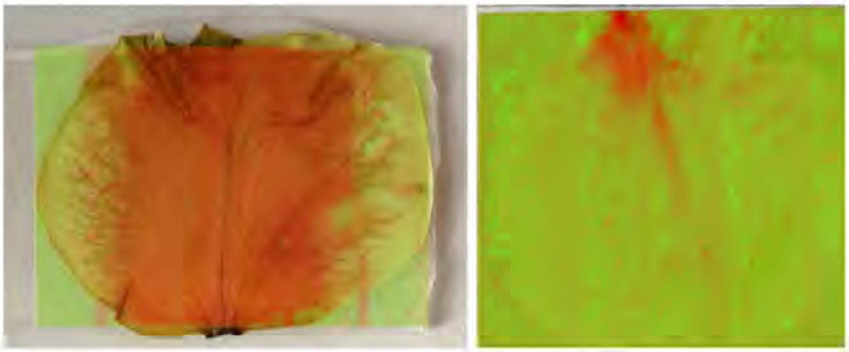

Fig. 1 Cu contamination in rose petals. Red color indicates the places of the emission of the 324 and 327 nm lines of Cu. The rose stem was placed in a copper sulfate solution for 24 hours. The outer petals are nearly completely contaminated with Cu (left), while in the inner petals Cu is only found in the veins (right).

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P55

Process analysis in lithium extraction by LIBS

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To move away from fossil energy sources, alternative energy storage technologies are required. At present, lithium-ion-based batteries are the most widespread and promising option. In lithium extraction, rapid and precise knowledge of the current elemental composition enables fast process adjustments, improving lithium yield and purity while reducing energy consumption and waste. At each stage of the extraction process, the composition must be determined for samples in various states of matter, including solids and liquids, and across a wide range of lithium concentrations. Inline Process Analytical Technology (PAT) aligns with the concept of interconnected and autonomous industrial production encompassed by the term Industry 4.0. Powerful analytical techniques such as inductively coupled plasma optical emission spectrometry (ICP-OES) provide accurate results but are time-consuming and require complex sample preparation. Faster techniques such as X-ray fluorescence spectroscopy (XRF) are not sensitive to light elements. In this context, LIBS appears to be a promising candidate, offering rapid and robust analysis with ideally no sample preparation. However, difficulties arise when analyzing complex solid samples due to significant matrix effects. Moreover, applying LIBS to aqueous samples presents additional challenges: plasma ignition in water generally requires higher energy, measurements in water are affected by pressure-induced line broadening, and probing the surface produces splashes that may damage the LIBS system. [1,2] Several strategies have been proposed to overcome these issues, including the use of double-pulse techniques and modification of the liquid's surface-to-volume ratio by forming micron-sized droplets or jets.

Direct analysis of aqueous samples is performed on droplets, liquid sheets, and jets with diameters in the micrometer range. Different nozzle geometries for sheets and jets are investigated. A microscope objective is used to focus the laser into a small volume and to increase energy density for liquid samples.

For probing low-concentration lithium solutions (e.g., saline solutions), fast enrichment strategies are useful, as they also enable complete removal of water and reduce matrix effects to some extent. Preconcentration of aqueous solutions on a well-defined region is achieved using a modified ring-oven method with minimal sample loss. [3] Another investigated approach, known as evaporative lithography, employs a mask with defined openings that enable localized evaporation, resulting in directed fluid flow. To the best of the author's knowledge, this method has not previously been applied in conjunction with LIBS. Both preconcentration techniques can be completed in under 10 minutes.

The aforementioned methods were investigated, and calibration procedures were developed. Multivariate calibration models are employed to address low lithium concentrations and strong matrix effects. The concentration limits achieved so far with enrichment are in the range of several hundred ppb, with signal intensity proportional to the solution concentration.

Keywords: inline PAT; lithium extraction; matrix effects; liquid LIBS

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P56

Tracer-assisted polymer identification using Laser Induced Breakdown Spectroscopy

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The growing demand for sustainable materials and improved recycling efficiency calls for reliable, rapid, and non-destructive methods to identify and trace plastic components throughout their life cycle. Within the framework of the EU Horizon project PRECYCLING [1], laser-induced breakdown spectroscopy (LIBS) is being explored as a versatile analytical tool to support these objectives and improving recycling efficiency through tracer-based material identification.

In this study, polymer samples containing Y_2O_3 and Tb_2O_3 oxide tracers at various concentrations were prepared and analyzed. LIBS measurements were conducted using a 1064 nm excitation source to detect tracer-specific emission lines. Additionally, polypropylene (PP) recyclates marked with Y_2O_3:Eu tracers (200 ppm) were blended with virgin PP at different weight ratios (10–90% recyclate) to simulate realistic recycling scenarios.

LIBS provided clear Yttrium emission signatures, enabling tracer detection below 100 ppm and reliable identification of marked recyclates even at low tracer levels (~20 ppm). Blind tests achieved 100% accuracy without interference from additives. These results demonstrate the suitability of LIBS as a fast, contactless method for tracer-assisted polymer identification, supporting advanced sorting and traceability in plastic recycling streams.

Keywords: LIBS, tracers, Y_2O_3:Eu, polymer recycling, polypropylene, material identification

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P57

Multi-Instrument LIBS Harmonization for Rare-Earth Element Imaging

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Rare-earth elements (REEs) present a demanding analytical challenge in LIBS due to their dense emission spectra, extensive line overlap, and strong matrix effects[1]. These factors complicate both elemental identification and quantification, while variations in instrumental configuration, optical alignment, or acquisition parameters further compromise spectral consistency across laboratories.

This study presents an interlaboratory evaluation of LIBS applied to REE-bearing minerals, carried out between laboratories in Portugal and the Czech Republic. Using shared reference samples, the work assesses the consistency of spectral features and imaging results across different LIBS setups. Machine-learning models are applied to process and classify spectra, promoting data interoperability and adherence to FAIR principles. The results identify key factors influencing data variability and propose best-practice guidelines for LIBS spectral imaging, contributing to the development of reliable, reproducible, and instrument-agnostic methodologies for REE analysis in geochemical and mineralogical studies.

Keywords: Multi-instrument Data; LIBS; Rare Earth Elements

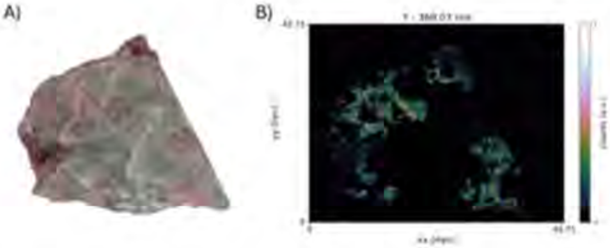

Fig. 1. Example of rock containing REEs. A) Rock from the Khibiny Mountains, Murmansk Oblast, Russia. B) Yttrium LIBS maps obtained by a Nd:YAG 1064 nm laser at 51 mJ, normalized to maximum intensity.

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ACKNOWLEDGEMENTS

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P58

Spectroscopic Pathways to Provenance: Insights into Metal Craftsmanship and Trade in Ancient Eastern Europe

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Metal artefacts unearthed through archaeological excavations frequently originate from complex cultural and exchange networks, reflecting trade, technological transmission, or the circulation of prestige goods. Although such objects may exhibit comparable typologies or even closely related elemental compositions, subtle analytical distinctions can reveal diverse production centers and technological practices.

The metal artefacts examined in this study originate from one of the most significant discoveries made in Transylvania, Romania, at the Tărtăria – Podu Tărtăriei Vest sites (hoards Tărtăria I and II) in the middle Mureş Valley. The Tărtăria I hoard (Cx 116) represents the largest and most complex assemblage of bronze and iron objects belonging to the so-called Bîlvăneşti–Vinţ series (horizon of bronze hoards VI = DFS VI). It is preliminarily dated to the Ha B3–C1 horizon and constitutes the earliest deposit of its kind uncovered through systematic archaeological excavation in the Carpathian region and the Middle to Lower Danube basin. Preliminary typological and metallurgical studies identified two principal categories of artefacts: bronze items—including *torques*, glass-type and knotted *fibulae*, bracelets, and *phalerae* used as costume or harness accessories—and iron artefacts such as weapons and tools. These objects may share morphological similarities and, in some cases, comparable elemental compositions, reflecting complex patterns of exchange, technological transmission, and long-distance trade within the region.

The present study applies Laser-Induced Breakdown Spectroscopy (LIBS) and Raman spectroscopy to discriminate between typologically similar metal artefacts and to investigate their compositional and technological variability. LIBS was employed in single-pulse configuration to explore stratigraphic and compositional depth profiles, while Raman spectroscopy provided complementary identification of corrosion products. The spectral datasets were processed using multivariate statistical methods, including Principal Component Analysis (PCA), to classify the artefacts according to compositional similarities and corrosion features. PCA revealed distinct patterns in the compositional space, suggesting potential shared production or recycling practices. Through the integration of spectroscopic data and statistical modelling, this study refines our understanding of the provenance, technological traditions, and exchange mechanisms underlying metal craftsmanship in ancient Eastern Europe.

Keywords: LIBS; Raman; provenance; archaeology

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P59

LIBS for quantitative Li monitoring in fluids for Li extraction and recycling

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The growing demand for lithium for battery production has increased interest in sustainable sources such as geothermal brines, which typically contain lithium concentrations of 100–200 ppm. A promising extraction approach is selective sorption in flow-through reactors, where lithium concentrations can vary from tens to several thousand ppm. Reliable process control therefore requires inline lithium monitoring, which is currently dominated by time-consuming laboratory techniques such as Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

We present an online method for quantitative lithium monitoring during extraction processes using LIBS with plasma ignition directly at the liquid surface. Initiating the breakdown at the liquid–gas interface causes the plasma to expand predominantly into the overlying gas phase, resulting in improved optical accessibility and increased signal strength compared to subsurface excitation.

The LIBS system is integrated into a bypass flow cell connected to the extraction reactor. A slight gas overpressure is applied inside the measurement cell to stabilize the liquid surface height of the flowing brine and compensate for pressure-induced fluctuations. The system operates in a pressure-resistant cell, enabling measurements under realistic geothermal process conditions at pressures up to 20 bar and temperatures up to 70 °C.

Measurements are performed at a repetition rate of 1 Hz, allowing laser-induced surface perturbations to fully dissipate between pulses. Continuous monitoring is demonstrated during a two-step lithium extraction process over 9 hours, covering lithium concentrations from 5–1200 mg/L.

This approach enables stable, continuous, and quantitative LIBS measurements at liquid surfaces under elevated pressure and temperature, establishing LIBS as a robust process analytical technology for inline lithium extraction monitoring.

Keywords: LIBS in Liquids; Direct Lithium Extraction; Inline Monitoring

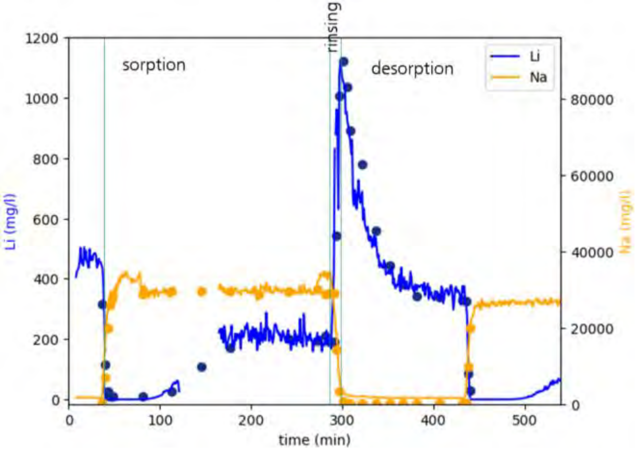

Fig. 1 Monitoring of the Li and Na concentration in a DLE process in a power plant at 15 bar, 50°C

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P60

Sensor for USP-Laser ablation control based on real-time plasma decay for up to 1 MHz repetition rate

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The increasing miniaturization of printed circuit boards (PCBs) demands highly precise manufacturing processes. With an increasing number of microvias required, there is significant potential for process improvement through inline regulation of the laser drilling process.

We present a single-line detector-based sensor system and its underlying measurement principle. The sensor monitors the temporal evolution of plasma throughout its entire lifetime, with particular focus on the dynamics of atomic emission lines and background radiation. Figure 1 a) illustrates the characteristic temporal behavior of copper plasma during laser drilling.

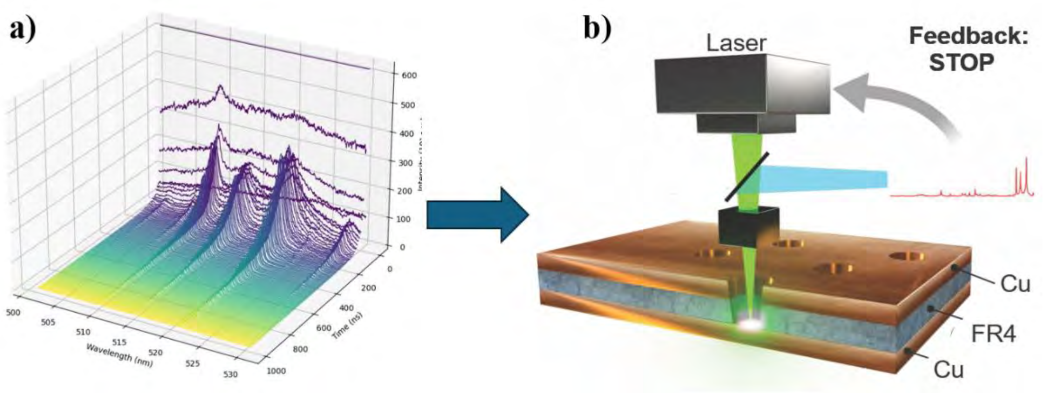

Fig. 1 a) Temporal behavior of a Cu fs-LIBS plasma at 670 µJ pulse energy **b)** Concept of the RAPID-LIBS

A clear distinction is observed: background radiation decays significantly faster than atomic emission lines. Based on this observation, our RAPID-LIBS sensor implements a signal processing approach where the initial signal phase is truncated to suppress background radiation, followed by integration of the atomic line signal. This generates both analog and digital output signals, enabling inline-capable real-time control of the laser drilling process. Beyond drilling applications, this system can be adapted for various other laser micromachining processes. The concept of the system is shown in Fig 1 b).

We examined the plasma lifetime of copper plasma under varying pulse energies, during which we identified a time-shifted peak in the 521.8 nm emission line. This peak likely correlates with plasma temperature, plasma density, and recombination rates. We present an analysis of these relationships and propose a physical explanation for this phenomenon.

Keywords: real-time plasma lifetime, laser micromachining, plasma decay, microvia drilling

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KEYNOTE

Demetrios Anglos is a Professor at the Department of Chemistry, University of Crete (UoC) and Associated Researcher at the Institute of Electronic Structure and Laser, Foundation for Research and Technology-Hellas (IESL-FORTH), where he leads the Applied Spectroscopy Laboratory (since 2001). He holds a B.Sc. in Chemistry (1986) from the University of Athens, Greece and a Ph.D. in Physical Chemistry (1994) from Cornell University, U.S.A. The activities of his research group focus on a) the study of photophysics in molecules and novel nanomaterials with potential sensing applications, and b) the applications of laser spectroscopic techniques (LIF, LIBS, Raman spectroscopy) in the analysis of materials, with particular emphasis on the development of mobile, field-deployable instrumentation for the study of archaeological objects and works of art, supporting analytical campaigns in museums and archaeological sites.

Prof. Dr. Reinhard Noll studied physics at the Technical University of Darmstadt, where he completed his doctorate in 1984. He co-founded the Fraunhofer Institute for Laser Technology (ILT) in Aachen in 1985. There he headed the department of laser measurement technology and was later head of the division for measurement technology and EUV radiation sources as well as member of the institute's management. He is a co-founder of ILT spin-off companies.
In 2012, he habilitated at RWTH Aachen University in the field of LIBS and received the venia legendi for "Laser Metrology for Inline Process Diagnostics." Since 2022, he has been head of the R&D department at Laser Analytical Systems & Automation GmbH in Aachen. With 196 scientific publications, 5 books, and 40 patents, he has made a significant contribution to the development of laser measurement methods and their industrial application.

Dr. Roberta Fantoni She holds a degree in Chemistry from Rome University La Sapienza. She spent all her career at ENEA, research center Frascati, where she covered the roles of head of the Laboratory Laser Applications, head of the Technical Unit Applications of Radiations, head of the Division Physical Technologies for Security and Heath Division. She retired July 1, 2022. She has been involved in multidisciplinary research activities focused on laser-matter interaction and projects implying knowledge relevant to both chemistry and physics such as laser spectroscopy: LIF, LIBS, Raman, material processing and nanotechnology, industrial and environmental laser diagnostics, including local and remote characterization of Cultural Heritage. ENEA member in E-RIHS.it and in the Centre of Excellence of the District of Technologies for Culture of Latium Region until December 2022, leading projects addressed to technology transfer from research institutes to conservators and restores. Author of 188 papers on international journals and 31 book chapters.

Mohamad Sabsabi earned his Ph.D. in Physics from the Université de Paris XI in 1988. Following his postdoctoral research on thermal plasmas, he joined the National Research Council of Canada (NRC) in 1992, where he pioneered activities in laser plasma spectroscopy and laser-induced breakdown spectroscopy (LIBS) in Canada. Dr. Sabsabi holds 25 patents and has a record of more than 600 publications (articles and conferences) covering both the fundamental science and industrial applications of laser-induced plasmas. Working with his team, he successfully implemented LIBS technology for a wide range of applications. His innovations have led to the creation of three spin-off companies and enabled ten technology transfers, applying LIBS in industries including mining, agriculture, metallurgy, pharmaceuticals, and manufacturing. He initiated and led the High Efficiency Mining (HEM) program for five years, aiming to enhance the mining value chain through the development of advanced sensors, process technologies, and new materials. Dr. Sabsabi has served on the editorial advisory boards and as guest editor for Spectrochimica Acta B, Analytical and Bioanalytical Chemistry (ABC), Applied Optics (AO), and Applied Spectroscopy. He chaired the LIBS2006 conference in Montreal, and has been vice-chair and co-organizer of several international LIBS conferences. His contributions have been recognized with several awards, including the LIBS Award at the LIBS Summit in Beijing (2019) for fundamental research, and the LIBS 2021 nomination for quantitative applications. Over his more than 33 years at NRC, he has held numerous leadership roles and is currently serving as a Principal Research Officer, leading the development of a new sensor technology platform.

INVITED SPEAKER

ARNAUD BULTEL, UNIVERSITÉ DE ROUEN, FRANCE : *HOW THE MODELLING CAN CONTRIBUTE TO A BETTER UNDERSTANDING OF THE UNDERLYING PHYSICS OF LIBS*

CHRISTOPH GERHARD, UNIVERSITY OF APPLIED SCIENCES AND ART HILDESHEIM / HOLZMINDEN / GÖTTINGEN, HILDESHEIM, GERMANY : *QUANTIFYING MANUFACTURING-INDUCED NEAR-SURFACE DEVIATIONS IN CHEMICAL COMPOSITION OF GLASSES VIA CALIBRATION-FREE LIBS*

ALFRED VOGEL, UNIVERSITY OF LÜBECK, GERMANY : *INTERPLAY OF LASER-INDUCED PLASMA FORMATION AND HYDRODYNAMIC EFFECTS IN BULK LIQUID AND AT A TARGET SURFACE IN AIR*

JHANIS GONZALEZ, LAWRENCE BERKELEY, USA : *INNOVATIVE ADVANCES IN LASER-INDUCED BREAKDOWN SPECTROSCOPY: ENHANCING SENSITIVITY, PRECISION, AND APPLICATIONS*

PAVEL PORIZKA, BRNO UNIVERSITY OF TECHNOLOGY, CZECH REPUBLIC : *BEYOND LIBS, MERGING MODALITIES TO GAIN MORE COMPREHENSIVE INFORMATION*

LUDOVIC DUPONCHEL, UNIVERSITÉ DE LILLE, FRANCE : *EXPLORING LIBS IMAGING AT SCALE: HOW CHEMOMETRICS CHANGES WHAT WE CAN SEE*

CÉCILE FABRE, UNIVERSITÉ DE LORRAINE, FRANCE : *FROM HANDHELD LIBS ANALYSIS TO µLIBS HIGH-RESOLUTION IMAGING: APPLICATIONS IN SULFOSALT MINERAL CHARACTERIZATION*

MARCELLA DELL'AGLIO, INSTITUTE FOR PHOTONICS AND NANOTECHNOLOGIES (CNR-IFN), ITALY : *LASER-INDUCED PLASMA AND BIOSENSING: COUPLING LASER-INDUCED BREAKDOWN SPECTROSCOPY WITH LATERAL FLOW IMMUNOASSAY*

YE TIAN, CHINA OCEAN UNIVERSITY, CHINA : UNDERWATER LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) TOWARDS DEEP-SEA APPLICATIONS

CRISTINA MÉNDEZ-LÓPEZ UNIVERSITY OF OVIEDO, SPAIN, DETERMINATION OF TOTAL FLUORINE IN ORGANIC LIQUID MATRICES: ON THE ROAD TO GASOLINE SCREENINGS

VINCENT MOTTO-ROS LYON UNIVERSITY, FRANCE, ELEMENT-SPECIFIC CHALLENGES AS A DRIVING FORCE FOR µ-LIBS IMAGING

ORGANISERS

The Centre for Research and Restoration of French Museums (C2RMF) is a national service of the Ministry of Culture serving 1,220 state-approved museums distinguished by the designation “Musées de France.” The C2RMF's key activities focus on the study of works of art at both a national and regional level. Equipped with world-class experimental facilities that are constantly being improved, like the particle accelerator AGLAE, the C2RMF focuses its research on several key areas: the physical and chemical characteristics of materials, the ageing of materials, database management, image analysis, digitisation and 3D modelling. They also have knowledge and experience of the capture of 3D data from many different types of artefacts. Furthermore, it has launched an open-source database management system that provides multilingual access (17 languages) to specialized vocabularies for the cultural museum sector and a semantic interface to browse the results. C2RMF also carries out scientific studies and data recording for these collections, and is active both nationally and internationally in the field of cultural heritage conservation and analysis. The C2RMF is involved in the development of technologies and scientific procedures employed in the preservation of art works and artefacts, both on its own and in partnership with other museums and research institutions across the globe.

The Fondation des Sciences du Patrimoine (Foundation for Heritage Science) is a partnership foundation under the Ministry of Culture and the National Center for Scientific Research (CNRS), initially created to oversee the governance of the LabEx (Laboratory of Excellence) Patrima and the EquipEx (Equipment of Excellence) Patrimex. Starting in 2018, the Foundation manages the Material Cultural Heritage: Knowledge, Heritage Preservation, and Transmission program within the Humanities, Creation, and Heritage University Research School.

Its ambition is to structure and finance research on tangible cultural heritage, with three main areas of focus:

- detailed knowledge of heritage
- improvement of conservation and restoration processes
- improvement of techniques for disseminating knowledge

In just a few years, the FSP has supported dozens of doctoral contracts, postdoctoral contracts, and master's scholarships, and has helped organize numerous scientific events, establishing itself as a leading player in the Paris region in the field of material heritage research. It helps to bridge the gap between the academic world and the sphere of heritage professionals by offering specialists from a variety of institutional backgrounds a framework and the means to carry out jointly defined research projects. The promotion of new synergies and working practices also applies from a disciplinary point of view: the projects supported bring together all disciplines, from history to computer science, including physical and chemical sciences, mathematics, law, and anthropology.

These projects contribute to a deeper understanding of heritage and an improvement in conservation and restoration processes. They bring to the fore heritage objects that are still little known or poorly understood in terms of their production and dissemination, as well as collections that are poorly defined from a scientific point of view.

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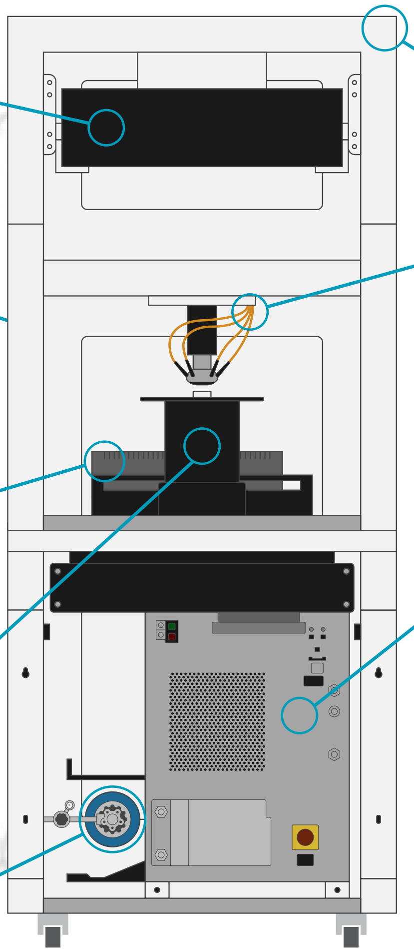
Elemental Insight

High-speed Elemental Imaging | 1k Hz LIBS Imaging



HEPA Filtration Unit

- Ensures clean and safe laboratory conditions by filtering dust from LA process

Robust Beam Delivery System

- Simple yet efficient beam delivery system including robust mirrors and lenses
- Sealed and purged with N_2
- Robust for hundreds of millions of laser shots

LIBS Detection Module

- 5 or 6 channel CMOS-based spectrometer array
- Optional iCCD detection

200 mm x 200 mm XY Stage

- High speed imaging of large samples at 400 mm per second
- Linear encoders for high accuracy pixel placement
- Optional 300 mm Y axis

Onboard Gas Storage

- Onboard storage of ArF and He cylinders

Mobile and Compact Cart

- Rugged, cart-based system ensures Elemental Insight can be moved as desired without risk of misalignment

Multi-fiber Light Collection

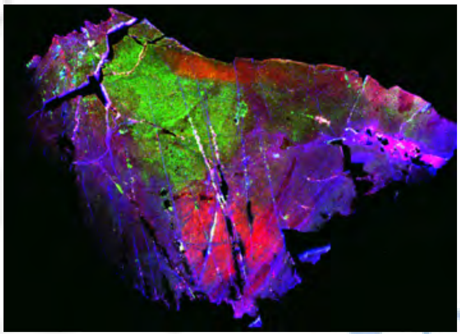
- Dedicated light collection optics and transport per channel leads to lowest LOD's
- Robust collection optics less susceptible to misalignment

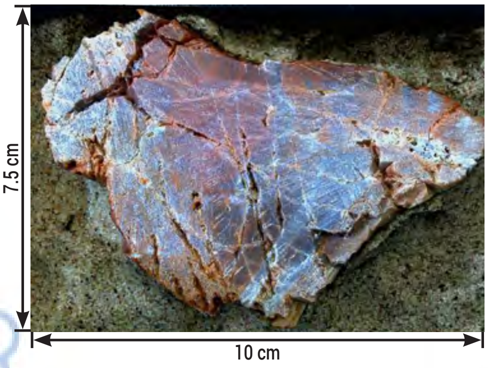
193 nm, 1000 Hz Excimer Laser Source

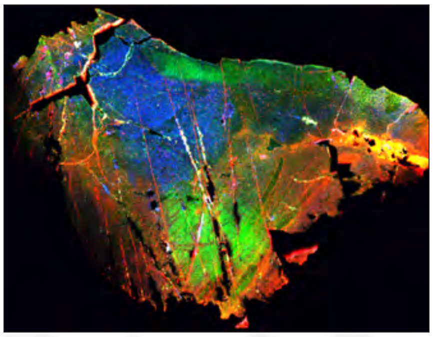
- Efficient coupling with a wide variety of sample types
- Provides low LOD's
- Enables high speed imaging at 1000 pixels per second

Simple UI with Onboard Data Processing

- ESL's ActiveView2 control software including iolite data processing and image generation







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Tel: + 406 586 3159 | lasers@icpms.com | www.icpmslasers.com

25130UFM

OceanOptics

We Measure What Matters

Specifications	ST	SR	HR
Wavelength Range	185 – 650 nm	185 – 1100 nm	190 – 1100 nm
Integration time	3.8 ms – 6 s	1 µs – 2 s	1 µs – 2 s
Optical resolution (FWHM)	2.2 nm	0.42 – 11.52 nm	0.08 – 7.12 nm
SNR (single scan @ 10 ms)	190:1	380:1	380:1
SNR (max. per second w/High Speed Averaging Mode)	2,250:1	25,800:1	25,800:1
Connectors	SMA 905 (input fiber)	16 pin Samtec TFM, RS-232, SMA, USB Type-C	SMA, TFM-108-02-L-DH Samtec, USB Type-C
Physical dimensions	42.1 x 40.3 x 26.6 mm	88.1 x 63.5 x 31.45 mm	148.8 x 106.4 x 48.2 mm
Weight	70.4g	275 g	0.9306 kg
Temperature (operation)	0 °C – 55 °C	0 °C – 55 °C	0 °C – 55 °C
Temperature (storage)	-30 °C – 70 °C	-30 °C – 70 °C	-30 °C – 70 °C
Best for	UV-vis absorbance of biological samples (blood, DNA/RNA)	High light-level absorbance measurements	Atomic emission line identification

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3500 Quadrangle Blvd. Orlando, FL 32817 USA

OceanOptics

Specifications	QE Pro	NR
Wavelength Range	190 – 1100 nm	900 – 1650 nm
Integration time	8 ms – 10 min	1 ms – 120 s
Optical resolution (FWHM)	1.2 – 6.87 nm	2.8 – 11.06 nm
SNR (single scan @ 10 ms)	1,000:1	13,000:1
SNR (max. per second w/High Speed Averaging Mode)	NA	-
Connectors	SMA 905 (input fiber)	SMA 905 (input fiber)
Physical dimensions	182 x 110 x 47 mm	182 x 110 x 47 mm
Weight	1.15 kg	0.9306 kg
Temperature (operation)	0 °C – 55 °C	10 °C – 35 °C
Temperature (storage)	-30 °C – 70 °C	-30 °C – 70 °C
Best for	UV absorbance of proteins	Biological sample and tissue analysis

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SpitLight
Scientific Lasers

SPITLIGHT EVO

FEATURES

- Up to 100 W average power (1 J @ 100 Hz)
- Versions with improved pulse-to-pulse stability and smooth gaussian beam profile available
- Reliable high-rep-rate performance with up to 1 kHz
- Marketleading diode lifetime
- Excellent size-to-power ratio
- Robust and stable monolithic design
- Easy scalability: EVO I to IV
- System can be injection seeded

INNOLAS LASER

SPECTRAL
INDUSTRIES

CorePulse

Integrate fast elemental analysis into your system

Autofocusing

Automatically focuses over a range of 50 mm so even highly complex profiles can be scanned with precision.

Plug & Play

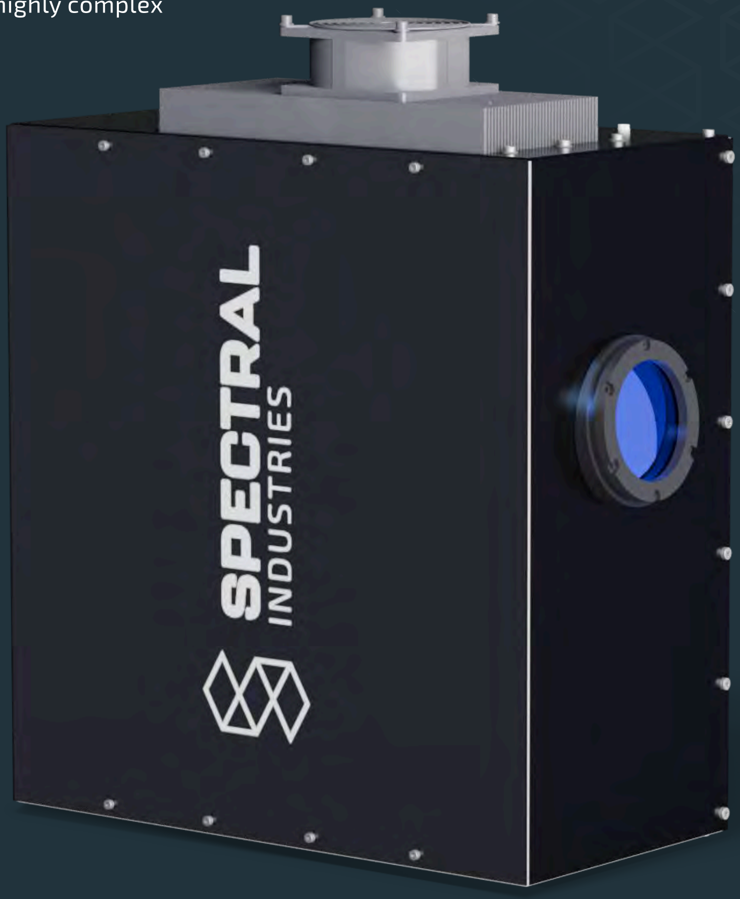
Delivered with documented software and hardware development kit and full support.

Robust

Field-proven sensor easily adjustable to any product or system application.

Fast

Supports sampling rates up to 1kHz for time-sensitive analysis.



What is CorePulse?

The CorePulse OEM LIBS analyzer enables seamless integration into customer systems, providing instant qualitative insights and supporting calibration for quantitative results. Compact and lightweight, it's an all-in-one, user-friendly solution adaptable to various sample types.

Key features include autofocusing, 100-500 µm spot size, a broad spectral range (190–967 nm), and fast kHz-rate sampling for high-performance analysis. Leveraging advanced LIBS sensor technology, CorePulse can measure nearly every element on the periodic table, including low atomic number elements such as hydrogen (H), carbon (C), sodium (Na), and lithium (Li).

CorePulse Specifications

An adaptable and robust OEM LIBS sensor that delivers reliable elemental data for faster, smarter performance of your mining and recycling applications. CorePulse customers benefit from plug-and-play design, which seamlessly integrates with core scanners, autonomous vehicles, in-line measurement systems, robotic manipulators, and much more...

Input voltage	24V DC
Max. Input current	12 A
Max. Measurement Frequency	1000 Hz
Laser Specifications	Pulse energy: 1 mJ Wavelength: 1064 nm
Spectrometer Specifications	**Range**: 190 nm - 967 nm **Spectral Resolution** UV: 0.16 nm (FWHM) - VIS: 0.34 nm (FWHM)
Analysis Specifications	All major elements including light elements (H, Li, C, Na, Mg, Ca, etc)
Stand-off Distance	Option A: 90 mm Option B: 205 mm
Autofocus range	± 25 mm
Software Control	Application Programming Interface with DLL
Laser Safety	Class 4
Ingress Protection	IP 51 - Connection available to integrate external interlock. Internal safety shuitter available.
Environmental	Operating temperature: 15 to 35°C Storage temperature: 0 to 40°C Humidity: < 90% (non-condensing)
Mounting	External 3-point mounting interface (M12)
Connectivity Interfaces	Data: M12 X-coded, 1GBps Trigger: BNC TTL
Maintenance & Calibration	Calibration: Can be provided upon request Maintenance: Regular window cleaning and cooling fins in case of dirty environment. Additional services as per support packages.
Weight & Dimensions (L x W x D)	Dimension: 386 x 476 x 190 mm Weight: 23 kg

Let's discuss your project needs.

Get in touch →

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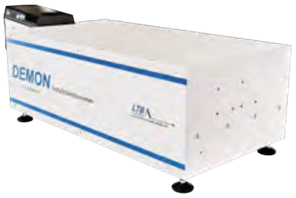
SPECTRAL
INDUSTRIES

LIGHT. PRECISION. ANALYTICS

SPECTROMETERS

Compact and high-resolution echelle spectrometer series for scientific and industrial applications

- f/7-f/10
- 5,000-50,000 (λ/ΔλFWHM)
- 50-5 pm (λ/ΔR) at 250 nm
- 190-1,070 nm (λmax range)
- max. 740 nm (λsimul)



Very high-resolution and optical throughput echelle spectrometer for isotope spectroscopy and laser quality control

- f/10
- 60,000-200,000 (λ/ΔλFWHM)
- 3.3-1.3 pm (λ/ΔR) at 250 nm
- 190-1,700 nm (λmax range)
- 1-13.5 nm (λsimul)

Worldwide unique echelle spectrometer series for the spectral characterization of emission and absorption lines

- f/50
- 1 million-6.5 million (λ/ΔλFWHM)
- 78-30 fm (λ/ΔR) at 193 nm
- 190-1,100 nm (λmax range)
- 8-400 pm (λsimul)

LIBSLAB

Chemical multi-elemental analysis in modular benchtop design

- Customized setup: spectrometer, laser, LIBSpector sample chamber, PC
- Chemical analysis by means of laser-induced breakdown spectroscopy (LIBS)
- For solid, liquid and gaseous samples
- Sample mapping with short measurement times
- Flexible range of applications in industry and science

CORALIS

Combined Raman & LIBS System

- Elemental composition or chemical structure
- Material identification, classification or quantification
- High quality sample imaging with micrometer resolution
- Particles or surfaces
- Solid samples or liquids
- Single spots or area scans

CALIBSO

All-in-one LIBS System

- High-quality sample imaging with micrometer sized resolution, single spot measurements or area scans
- Durable diode pumped laser with a spot size of ~100µm on sample surface for high spatial resolution
- High-resolution echelle spectrometer with spectral resolving power in the pm-range and a large simultaneous wavelength range
- Material identification, classification and quantification of bulk materials or surfaces with univariate or multivariate data analysis

ABLATOM
ELEMENTAL LASER SOLUTIONS

LIBS TECHNOLOGY

Advanced elemental analysis solutions

ABLASCAN™ : HIGH-RESOLUTION LIBS IMAGING & ELEMENTAL MICRO-ANALYSIS

A LIBS PLATEFORM FOR FAST, QUANTIATIVE AND SPATIALLY RESOLVED ELEMENTAL ANALYSIS

OVERVIEW

ABLASCAN™ is a high-performance LIBS platform designed for micrometric-scale elemental imaging, high-frequency spectral acquisition, and quantitative multi-element analysis. Its optical architecture enables stable plasma generation, broadband spectral detection, and precise spatial control, making it suitable for advanced research in materials science, geochemistry, metallurgy, battery technologies and recycling.

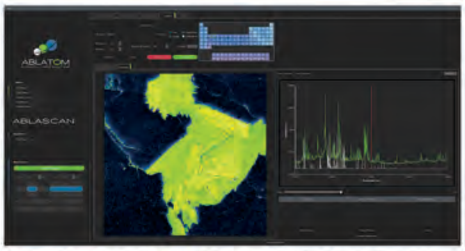
ADVANTAGES

High-Speed Spectral Acquisition
10–1000 spectra/s
1 million measurement in 15 minutes

Full Elemental Detection Range
Broadband spectrometers enabling detection from light to heavy elements
High sensitivity for Li, C, Be and other low-Z species
Multi-layer and multi-material capability

Micrometric Chemical Imaging
Spatial resolution down to a few micrometers
Scanning areas up to 200 cm²
Real-time generation of 2D/3D chemical maps

Advanced Data Processing
Automated peak identification
Quantification via calibration curves or chemometric models
Machine learning for material classification and anomaly detection

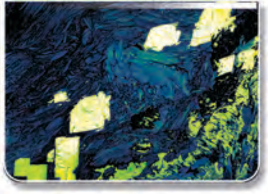


Intuitive interface with automatic identification algorithms and data processing

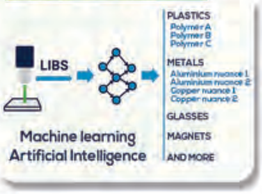
WHAT MAKES ABLASCAN™ A SCIENTIFIC INSTRUMENT?

Spectral analysis

Chemical imaging



Material recognition



- **Stable, repeatable plasma generation**
- **High-dynamic-range detection for trace and major elements**
- **Configurable optical modules**
- **Robust mechanical design**
- **Full data export for scientific workflows**

APPLICATION DOMAINS

- Geosciences & Mineralogy
- Battery Materials
- Materials Science & R&D
- Metallurgy & Surface Engineering
- Recycling & Circular Materials

ABOUT ABLATOM

ABLATOM is a French company that designs, manufactures, and distributes advanced LIBS solutions in France and internationally. From laboratories to industrial processes, our mission is to provide robust and high-performance analytical tools for scientific research and strategic industrial sectors.

CONTACT

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