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ISSI/ISSI-BJ Joint Call for Proposals 2018
International Teams in Space and Earth Sciences

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

Summary of the project :

A revolutionary technique for planetary science: Laser-induced Breakdown Spectroscopy (LIBS) is an active analytical technique that makes use of a pulsed laser to ablate material of interest at a distance. The atoms in the high temperature plasma emit at specific wavelengths from the UV to near-IR and the light can be analyzed by spectrometry to determine the composition of the target [1]. Since 2012, LIBS has been successfully used under low atmospheric pressure for exploring the geology of Mars at Gale Crater with the Mars Science Laboratory rover's ChemCam instrument [2-4]. LIBS can be used to analyze single regolith mineral particles and larger rocks, giving major and minor elements compositions. Moreover, LIBS is sensitive to volatile elements (H, Na, etc.) that are of intrinsic interest to understand key planetary processes. The generated shock wave can also ablate dust covering rocks to allow further analysis by other instruments on the mission platform (rover, lander). In order to quantify the elemental composition of various targets, large laboratory samples analyses are required for calibration, with ChemCam's calibration database containing more than 400 standards [5-6].

LIBS is becoming international: Due to its ease of deployment and rapidity of analysis, LIBS has shown a great potential as a chemistry survey instrument for the next generation of in situ space missions to planets, satellites and small bodies. In the next couple of years, three more LIBS space instruments will be sent for planetary exploration by teams representing several different nationalities In 2018, the Indian space mission to the Moon Chandrayaan 2 will comprise a rover equipped with a small portable LIBS instrument for regolith reconnaissance around the landing site [7]. In 2020, the next NASA Mars rover will carry the SuperCam instrument, a follow-up of the ChemCam instrument, which will combine the LIBS technique with Raman and IR analyses for mineralogical assessment [8] in a collaboration involving several different European countries. Finally, the China Academy of Space Technology is developing a combined orbiter and rover mission for exploring Mars by 2020 [9]. The Chinese rover will also be equipped with a LIBS survey instrument. In the framework of these near future missions, it is important to develop strategies to assess the potential for combined analysis of these different in situ instruments.

Goals of the ISSI International Team: In the framework of the ISSI/ISSI-BJ Joint Call for Proposals 2018 for International Teams in Space and Earth Sciences, we intend to submit a proposal to gather a team of LIBS specialists from all the major countries currently involved in the use of LIBS for space exploration (USA, Europe, Japan, India, China) to meet and exchange information during a couple of workshops in 2018-2019.

The goals of the team will be fourfold:

1. Assess the potential for combined analysis of the data by sharing and discussing the technical details of each instrument design.
2. Discuss the calibration procedures of each instrument and share the relevant tools (databases, software, calibration targets, etc.) to determine the best methods to develop potential cross-calibration between the four instruments.
3. Develop and share the tools necessary for comparing the analyses made by the four instruments for the 2020 timeline, as an international effort.
4. Define a set of recommendations to facilitate the use of the technique for future planetary missions.

ISSI being located both in Bern and in Beijing will provide ideal facilities to allow fruitful interactions and meetings between the members from the different countries involved in such projects. We plan to propose one meeting in each ISSI location (Beijing and Bern) for maximum benefit to the international nature of the team. Of course, all team members are committed to attending the meetings in both locations.

Research domain: Planetary Sciences

References:

[1] Cremers D.A. and Radziemski L.J. (2006) *Handbook of Laser-Induced Breakdown Spectroscopy*.

[2] Wiens R.C. et al. (2012) *SSR DOI :* 10.1007/ s11214-012-9902-4.

[3] Maurice S. et al. (2012) *SSR*, DOI: 10.1007/ s11214-012-9912-2.

[4] Maurice S. et al. (2016) *JAAS*, DOI: 10.1039/ c5ja00417a.

[5] Wiens R. C. et al. (2013) *Spectrochimica Acta Part B: Atomic Spectroscopy*, *82*, 1-27.

[6] Clegg S. M. et al. (2017) *Spectrochimica Acta Part B: Atomic Spectroscopy*, *129*, 64-85.

[7] Laxmiprasad et al. (2013) *ASR, 52(2)*, 332

[8] Wiens R. C. et al. (2017) *Spectroscopy*, *32*(5), 50-55.

[9] https://gbtimes.com/china-reveals-more-details-its-2020-mars-mission

1. Scientific rationale, timeliness and goals

Scientific context

Laser-induced Breakdown Spectroscopy (LIBS) is an active analytical technique that makes use of a pulsed laser to ablate material of interest at a distance. The atoms in the high temperature plasma emit at specific wavelengths from the UV to near-IR and the light can be analyzed by spectrometry to determine the composition of the target (Cremers and Radziemski, 2006). The technique is routinely used to analyze materials on Earth for industrial and scientific purposes. However, geological applications remain challenging.

Since 2012, LIBS has been successfully used under low atmospheric pressure for exploring the geology of Mars at Gale Crater with the Mars Science Laboratory rover's ChemCam instrument (Wiens et al. 2012; Maurice et al. 2012; 2016). ChemCam can be used to analyze single regolith mineral particles and larger rocks, giving major and minor elements composition. Moreover, LIBS is sensitive to volatile elements (H, C, Na, etc) that are of intrinsic interest to understand key planetary processes and potential habitability. The generated shock wave can also ablate dust covering rocks to allow further analysis by other instruments on the mission platform (rover, lander).

The LIBS signal is dependent on the instrumental configuration used (laser pulse duration and focus) and the environmental conditions under which the plasma is generated (atmospheric pressure and composition). Preprocessing of the signal includes denoising, background removal, wavelength calibration, instrumental response correction, and Earth to Mars correction based on on-board calibration targets signals (Wiens et al. 2013).

In order to quantify the elemental composition of various targets, large laboratory samples analyses are required for calibration, with ChemCam's calibration database containing more than 400 standards (Wiens et al. 2013; Clegg et al. 2017). Major elements compositions are usually predicted using multivariate data analysis tools. In the case of ChemCam, initially Partial Least Squares was used, but further refinements include the use of Independent Components Analysis regression and multi regression coefficients (Anderson et al. 2017, Clegg et al. 2017). Additionally, a database of LIBS emission lines under martian conditions was generated from laboratory measurements to facilitate minor elements monitoring for the mission (C-quest software, Cousin 2012).

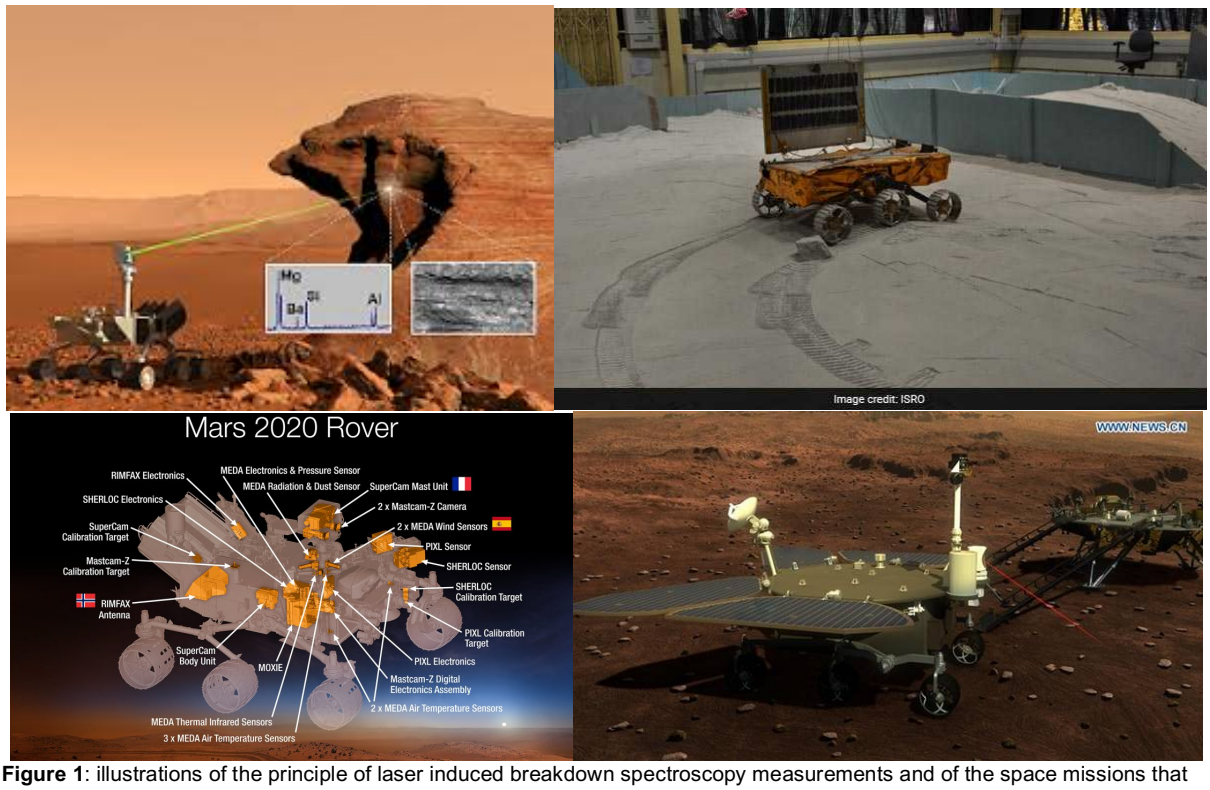

Figure 1: illustrations of the principle of laser induced breakdown spectroscopy measurements and of the space missions that will deploy this capability in the 2020 timeframe. a. ChemCam instrument on-board Mars Science Laboratory (Credit CNES) b. Chandrayaan 2 ISRO rover tests in the laboratory in preparation for launch (Credit ISRO) c. SuperCam on-board the NASA Mars 2020 rover (Credit: NASA) d. The Chinese Mars rover for 2020 equipped with the LIBS laser (Credit CNSA).

Programmatic context and timeliness

Due to its ease of deployment and rapidity of analysis, LIBS has shown a great potential as a chemistry survey instrument for the next generation of in situ space missions to planets, satellites and small bodies. In the next couple of years, three more LIBS space instruments will be sent for planetary exploration by teams representing a number of different nationalities. In 2018, the Indian space mission to the Moon Chandrayaan 2 will comprise a rover equipped with a small portable LIBS instrument for regolith reconnaissance around the landing site [7]. In 2020, the next NASA Mars rover will carry the SuperCam instrument, a follow-up of the ChemCam instrument, which will combine the LIBS technique with Raman and IR analyses for mineralogical assessment (Wiens et al. 2017) as part of a consortium involving several European countries. Finally, the China Academy of Space Technology is developing a combined orbiter and rover mission for exploring Mars by 2020 (https://gbtimes.com/china-reveals-more-details-its-2020-mars-mission). The Chinese rover will also be equipped with a LIBS survey instrument.

In the future, further space missions to study other planetary surfaces will likely include this capability as well. Venus space missions have already been proposed to carry combined LIBS-Raman instruments, while the small bodies and icy satellites are other suitable targets of high interest in the future for astrobiological exploration (asteroids, comets, Titan, Europa, etc.). The capability of quick survey for most elements with a LIBS instrument will prove essential for the success of the future missions, especially if one of the goals is to return a sample from the surface.

Scientific rationale

In the framework of near-future and future missions, it is important to develop strategies to assess the potential for combined analysis of the different in situ instruments and possible sharing of data and tools to facilitate the interpretation of the results. Our international team of experts will therefore dedicate its efforts to define the capabilities of LIBS for the different types of planetary missions and start developing and sharing the tools necessary for the interpretation of the data.

Goals of the Working Group

In the framework of the ISSI/ISSI-BJ International Teams in Space and Earth Sciences framework, we intend to gather a team of LIBS specialists from all the major countries currently involved in the use of LIBS for space exploration (USA, Europe, Japan, India, China) to meet and exchange information during a couple of workshops in 2018-2019.

The goals of the team will be fourfold:

1. Assess the potential for combined analysis of the data by sharing and discussing the technical details of each instrument design.
2. Discuss the calibration procedures of each instrument and share the relevant tools (databases, software, calibration targets, etc.) to determine the best methods to develop potential cross-calibration between the four instruments.
3. Develop and share the tools necessary for comparing the analyses made by the four instruments for the 2020 timeline, as an international effort.
4. Define a set of recommendations to facilitate the use of the technique for future planetary missions.

2. Expected output of the project

1. Write a report and review paper on the methods for calibration and cross-calibration of LIBS instruments. Create a database of relevant resources available online for this purpose.
2. Develop and share online the tools necessary for comparing the analyses made by the four instruments for the 2020 timeline, as an international effort. One such tool is a library of LIBS emission lines under different planetary conditions. The software already exists for Mars applications (C-quest, Cousin 2012). Updates to the current version and a lunar and Venus addition could be envisioned within the timeframe of the working group. A publication in the form of a user manual would be published in a relevant scientific journal.
3. A comparison of calibration databases used from Earth-based laboratory experiments. A comparison and definition of sets of relevant calibration targets for the respective instruments. Define a general set of calibration recommendations for planetary LIBS. This could also be published as a paper.
4. Prepare a report on the specific use of the techniques for planetary exploration and outline the advantages and scientific goals of the instruments for different planetary bodies for future exploration. The report would define a set of recommendations to facilitate the use of the technique for future planetary missions and would be published in a relevant scientific journal as well as for executive information.

3. Added value provided by ISSI and ISSI-BJ

ISSI being located both in Bern and in Beijing will provide ideal facilities to allow fruitful interactions and meetings between the members from the different countries involved in such projects. We plan to propose one meeting in each ISSI location (Beijing and Bern) for maximum benefit to the international nature of the team. Of course, all team members are committed to attending the meetings in both locations.

Facilities required

The team will need to have access to the internet during the meeting, to access the online archives of each respective agency or institute and to allow exchange of files, and codes via the websites dedicated to sharing the work.

4. List of confirmed team members

1. J. Lasue (IRAP, France; LIBS specialist, ChemCam and SuperCam, Team leader)
2. R. Wiens (LANL, USA, ChemCam and SuperCam PI, Team co-leader)
3. S. Clegg (LANL, USA, LIBS specialist, ChemCam and SuperCam)
4. A. Cousin (IRAP, France; LIBS specialist, ChemCam and SuperCam)
5. S. Kameda (Rikkyo University, Japan, PI of LIBS for MMX)
6. J. Laserna (Universita de Malaga, Spain)
7. Z. Ling (Shandong University, China, LIBS expert)
8. S. Maurice (IRAP, France, ChemCam and SuperCam deputy-PI)
9. X. Ren (National Astronomical Observatories, Chinese Academy of Sciences, LIBS expert)
10. S. Schroeder (DLR, Germany, LIBS expert)
11. P. Sobron (SETI Institute, LIBS expert)
12. X. Wan (Shanghai Institute of Technical Physics (SITP), Chinese Academy of Sciences (CAS), LIBS expert)

5. Calendar of activities and output

Dates	Activities	Institute
Summer 2018	Finalisation of schedule, creation of project webpage	all
Jan. 2019	One week workshop at ISSI-Bern: dedicated principally to comparing the instruments and preparing recommendations for planetary LIBS.	ISSI-Bern
Sept. 2019	Presentation of the review at EPSC, review paper to be submitted	all
Oct. 2019	One week workshop at ISSI-BJ: dedicated to principally to comparing the calibration procedures and defining the tools for cross-calibration	ISSI-BJ
Dec. 2019	Presentation of the final calibration at AGU or LPSC, associated paper to be submitted	all
Dec. 2019	New tools, databases and procedures shared online, preparation of dedicated publication on the work + report	all

Appendix 1 : References

Anderson, Ryan B., et al. "Improved accuracy in quantitative laser-induced breakdown spectroscopy using sub-models." *Spectrochimica Acta Part B: Atomic Spectroscopy* 129 (2017): 49-57.

Clegg, S. M., Wiens, R. C., Anderson, R., Forni, O., Frydenvang, J., Lasue, J., ... & McLennan, S. M. (2017). Recalibration of the Mars Science Laboratory ChemCam instrument with an expanded geochemical database. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *129*, 64-85.

Cousin, A. (2012). *LIBS (Laser-induced breakdown spectroscopy) pour l'exploration martienne* (Doctoral dissertation, Université de Toulouse, Université Toulouse III-Paul Sabatier).

Cremers D.A. and Radziemski L.J. (2006) *Handbook of Laser-Induced Breakdown Spectroscopy*. John Wiley & Sons.

Laxmiprasad, A. S., Raja, V. S., Menon, S., Goswami, A., Rao, M. V. H., & Lohar, K. A. (2013). An in situ laser induced breakdown spectroscope (LIBS) for Chandrayaan-2 rover: Ablation kinetics and emissivity estimations. *Advances in Space Research*, *52*(2), 332-341.

Maurice, S., Wiens, R. C., Saccoccio, M., Barraclough, B., Gasnault, O., Forni, O., ... & Bernardin, J. (2012). The ChemCam instrument suite on the Mars Science Laboratory (MSL) rover: Science objectives and mast unit description. *Space Science Reviews*, *170*(1-4), 95-166.

Maurice, S., Clegg, S. M., Wiens, R. C., Gasnault, O., Rapin, W., Forni, O., ... & Nachon, M. (2016). ChemCam activities and discoveries during the nominal mission of the Mars Science Laboratory in Gale crater, Mars. *Journal of Analytical Atomic Spectrometry*, *31*(4), 863-889.

Wiens, R. C., Maurice, S., Barraclough, B., Saccoccio, M., Barkley, W. C., Bell, J. F., ... & Bouyé, M. (2012). The ChemCam instrument suite on the Mars Science Laboratory (MSL) rover: Body unit and combined system tests. *Space Science Reviews*, *170*(1-4), 167-227.

Wiens, R. C., Maurice, S., Lasue, J., Forni, O., Anderson, R. B., Clegg, S., ... & Deflores, L. (2013). Pre-flight calibration and initial data processing for the ChemCam laser-induced breakdown spectroscopy instrument on the Mars Science Laboratory rover. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *82*, 1-27.

Wiens, R. C., Maurice, S., & Perez, F. R. (2017). The SuperCam remote sensing instrument suite for the Mars 2020 rover: a preview. *Spectroscopy*, *32*(5), 50-55.

Appendix 2 : CVs of team members

Curriculum Vitae: LASUE, Jérémie

Planètes, Environnements et Plasmas Spatiaux, Institute of Research in Astrophysics and Planetology, Toulouse, France

Role in the project: Team Lead

Current positions:

- Collaborator of the ChemCam remote LIBS instrument on the *Curiosity* Mars rover
- Collaborator of the SuperCam remote LIBS instrument for the NASA Mars 2020 rover
- Collaborator for the Venus Elemental and Mineralogical Camera (VEMCam LIBS) instrument development for the NASA New Frontiers Program
- Co-I of the CONSERT radar on-board the Rosetta mission

Education: PhD, U. of Paris, 2003; topic: Astrophysics
PhD, U. of Brussels, 2003; topic: Applied Sciences

Services in National and/or International Committees:

- NASA Mars proposal reviews; MEPAG, LEAG and SBAG participant;
- Member of the French Society for Astronomy and Astrophysics
- Member of the ESA review committee for the Rosetta End of Mission Data
- Lead and collaborator for the organization of international conferences on comet studies (2014-2016) and lunar symposium (2018)
- Science consultant for the 'extreme exploration' public exhibition for Rosetta and MSL at the Museum «Cité de l'Espace» in Toulouse, France

Honors:

- NASA Group Achievement Award, for the ChemCam team
- ESA «Certificate of outstanding contribution» to the ESA Rosetta Mission
- International Academy of Astronautics «Laurels for Team Achievement to the Philae lander Mission».
- Lavoisier scholarship for international Ph.D. studies from the French Ministry of Foreign Affairs.

Selected Publications:

Wiens R.C., et al. (2012) The ChemCam Instruments on the Mars Science Laboratory (MSL) Rover: Body Unit and Combined System Performance. Spa. Sci. Rev. 170, 167-227, doi 10.1007/S11214-012-9902-4.

Wiens, R. C., Maurice, S., Lasue, J., Forni, O., Anderson, R. B., Clegg, S., ... & Deflores, L. (2013). Pre-flight calibration and initial data processing for the ChemCam laser-induced breakdown spectroscopy instrument on the Mars Science Laboratory rover. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *82*, 1-27.

Maurice, S., Wiens, R. C., Saccoccio, M., Barraclough, B., Gasnault, O., Forni, O., ... & Bernardin, J. (2012). The ChemCam instrument suite on the Mars Science Laboratory (MSL) rover: Science objectives and mast unit description. *Space Science Reviews*, *170*(1-4), 95-166.

Lasue, J., Wiens, R. C., Stepinski, T. F., Forni, O., Clegg, S. M., & Maurice, S. (2011). Nonlinear mapping technique for data visualization and clustering assessment of LIBS data: application to ChemCam data. *Analytical and bioanalytical chemistry*, *400*(10), 3247-3260.

Lasue, J., Wiens, R. C., Clegg, S. M., Vaniman, D. T., Joy, K. H., Humphries, S., ... & Bender, S. (2012). Remote laser-induced breakdown spectroscopy (LIBS) for lunar exploration. *Journal of Geophysical Research: Planets*, *117*(E1).

Author and co-author on > 30 papers on planetary LIBS design and calibration.

Curriculum Vitae: WIENS, Roger
Space Remote Sensing, Los Alamos National Laboratory, Los Alamos, USA

Role in the project: Team Co-Lead
Current positions:
- Principal Investigator of the ChemCam remote LIBS instrument on the *Curiosity* Mars rover
- Principal Investigator of the SuperCam remote LIBS instrument for the NASA Mars 2020 rover
- Deputy Principal Investigator for the Venus Elemental and Mineralogical Camera (VEMCam LIBS) instrument development for the NASA New Frontiers Program

Education: PhD, U. of Minnesota, 1988; topic: Martian meteorites, Mars atmosphere
Services in National and/or International Committees:
- NASA CAPTEM sample allocations; MEPAG and VEXAG participant; US & foreign proposal reviews
- Co-lead of ISSI Working Group on Solar-Wind Composition, 2011-2013

Honors:
- R&D100 Invention Award, 2003, for combined LIBS-Raman instrument
- NASA Leadership Individual Award, as PI of ChemCam
- NASA Group Achievement Award, for the ChemCam team
- NASA Group Achievement Award, for the Genesis mission
- Chevalier de l'Ordre National Merite, 2016 (knighted by the office of the Science Minister of France for forging ties between the French and American scientific communities)
- Doctorus Honoris Causa, University of Toulouse, 2017
- Air and Space Academy Vermeil Medal, 2017
- Asteroid 41795 WIENS, named in 2017

Selected Publications:

Wiens R.C., et al. (2012) The ChemCam Instruments on the Mars Science Laboratory (MSL) Rover: Body Unit and Combined System Performance. Spa. Sci. Rev. 170, 167-227, doi 10.1007/S11214-012-9902-4.

Wiens R.C., et al. (2013) Pre-flight calibration and initial data processing for the ChemCam laser-induced breakdown spectroscopy instrument on the Mars Science Laboratory rover. Spectrochim. Acta B, 82, 1-27, doi.10.1016/j.sab.2013.02.003.

Wiens R.C., Maurice S., and Rull Perez F. (2017) The SuperCam remote sensing instrument suite for the Mars 2020 rover mission: A preview. Spectroscopy 32(5), 50-55.

Author and co-author on > 50 papers on planetary LIBS design and calibration.

Curriculum Vitae: CLEGG, Sam
Physical Chemistry and Applied Spectroscopy, Los Alamos National Laboratory, Los Alamos, USA

Role in the project: Team Member

Current positions:
- Principal Investigator for the Venus Elemental and Mineralogical Camera (VEMCam LIBS) instrument development for the NASA New Frontiers Program
- Co-Investigator of the ChemCam remote LIBS instrument on the *Curiosity* Mars rover
- Co-Investigator of the SuperCam remote LIBS instrument for the NASA Mars 2020 rover

Education: Ph.D. Physical Chemistry (Analytical Chemistry Minor), Indiana University, Bloomington, IN, 1999

Honors:
2017 NASA Group Achievement Award for MSL Extended Mission-1 Science and Operations Team
2015 NASA Group Achievement Award for MSL Prime Mission Science and Operations Team
2013 NASA Group Achievement Award for MSL ChemCam Instrument Development and Science Team
2013 LANL Distinguished Performance Award, for Mars-time ChemCam Operations

Selected Publications:
Samuel M. Clegg et al., "Recalibration of the Mars Science Laboratory ChemCam instrument with an expanded geochemical database," Spectrochimica Acta Part B, 2017, 129, 64–85

Ryan B. Anderson, Samuel M. Clegg, et al. "Improved accuracy in quantitative laser-induced breakdown spectroscopy using sub-models," Spectrochimica Acta Part B, 2017, 129 49–57

J. Colgan, E.J. Judge, H.M. Johns, D.P. Kilcrease, J.E. Barefield II, R.McInroy, P.Hakel, R.C. Wiens, S.M. Clegg, Theoretical modeling and analysis of the emission spectra of a ChemCam standard: Basalt BIR-1A, Spectrochimica Acta Part B, 2015, 110, 20–30

S. Maurice, S. M. Clegg, et al., "ChemCam activities and discoveries during the nominal mission of the Mars Science Laboratory in Gale crater", Mars, J. Anal. At. Spectrom 2016, 13, 823–1050

Samuel M. Clegg et al., "Planetary Geochemical Investigations Using Raman and Laser-Induced Breakdown Spectroscopy", Applied Spectroscopy, 2014, 68(9), 925-936

M. Nachon, S. M. Clegg, et al., "Calcium sulfate veins characterized by ChemCam/Curiosity at Gale crater", Mars, J. Geophys. Res. Planets, 2014, 119, doi:10.1002/2013JE004588.

S.M. Clegg et al., "Multivariate analysis of remote laser-induced breakdown spectroscopy spectra using partial least squares, principal component analysis, and related techniques", Spectrochim. Acta, Part B, 2009, 64, 79-88

S.K. Sharma, A.K. Misra, P.G. Lucey, R.C. Wiens and S.M. Clegg, "Combined Remote LIBS and Raman Spectroscopy of Sulfur-Containing Minerals, and Minerals Coated with Hematite and Covered with Basaltic Dust at 8.6 m", Spectrochim. Acta, Part A, 2007, 68, 1036

Curriculum Vitae: COUSIN, Agnes
Planètes, Environnements et Plasmas Spatiaux, Institute of Research in Astrophysics and Planetology, Toulouse, France

Role in the project: Team Member

Current positions:
- Astronomer at IRAP, Toulouse, France
- Collaborator of the ChemCam remote LIBS instrument on the *Curiosity* Mars rover
- Collaborator of the SuperCam remote LIBS instrument for the NASA Mars 2020 rover

Education: PhD in Planetary Science (University of Toulouse, January 27th, 2012). Thesis title : "Laser-Induced Breakdown Spectroscopy) for Martian exploration". No mention is assigned by Toulouse-III University.

Honors:
2017 NASA Group Achievement Award for MSL Extended Mission-1 Science and Operations Team
2015 NASA Group Achievement Award for MSL Prime Mission Science and Operations Team
2013 NASA Group Achievement Award for MSL ChemCam Instrument Development and Science Team

Selected Publications:

1. **Cousin A.** ; Dehouck, E. ; Meslin, P.-Y. ; Forni, O.; Williams, A. J. ; Stein, N.; Gasnault, O.; Bridges, N.; Ehlmann, B. ; Schröder, S. ; Payré, V. ; Rapin, W. ; Pinet, P. ; Sautter, V. ; Lanza, N.; Lasue, J. ; Maurice, S. ; Wiens, R. C. Geochemistry of the Bagnold dune field as observed by ChemCam and comparison with other aeolian deposits at Gale Crater , Journal of Geophysical Research (Planets) 122, pp. 2144-2162 (2017).
2. **Cousin A.** ; Sautter, V. ; Payré, V. ; Forni, O.; Mangold, N.; Gasnault, O.; Le Deit, L. ; Johnson, J. ; Maurice, S. ; Salvatore, M.; Wiens, R. C. ; Gasda, P. ; Rapin, W. Classification of igneous rocks analyzed by ChemCam at Gale crater, Mars , Icarus 288, pp. 265-283 (2017).
3. **Cousin A.** ; Meslin, P. Y. ; Wiens, R. C. ; Rapin, W. ; Mangold, N.; Fabre, C. ; Gasnault, O.; Forni, O.; Tokar, R. ; Ollila, A.; Schröder, S. ; Lasue, J. ; Maurice, S. ; Sautter, V. ; Newsom, H.; Vaniman, D.; Le Mouélic, S. ; Dyar, D.; Berger, G.; Blaney, D.; Nachon, M.; Dromart, G.; Lanza, N.; Clark, B. ; Clegg, S. ; Goetz, W. ; Berger, J. ; Barraclough, B. ; Delapp, D. Compositions of coarse and fine particles in martian soils at gale : A window into the production of soils Icarus 249, pp.22-42 (2017).
4. **Cousin A.** ; Sautter, V. ; Fabre, C. ; Maurice, S. ; Wiens, R. C. Textural and modal analyses of picritic basalts with ChemCam Laser-Induced Breakdown Spectroscopy , Journal of Geophysical Research 117 (2012).
5. **Cousin A.** ; Forni, A.; Maurice, S. ; Gasnault, O.; Fabre, C. ; Sautter, V. ; Wiens, R. C. ; Mazoyer, J. Laser induced breakdown spectroscopy library for the Martian environment , Spectrochimica Acta Part B 66 (2011).

NAME, First Name: KAMEDA, Shingo

Affiliation: College of Science, Rikkyo University

Role in the project: Team Member

Current position: Associate Professor (Professor from April 2018)

- Lead Co-I of the Mercury Sodium Atmosphere Spectral Imager (MSASI) on the BepiColombo Mercury Magnetospheric Orbiter
- Sub-PI of the Optical Navigation Camera (ONC) on the *Hayabusa2* spacecraft
- Project Manager (PM) of the telescopic camera (TENGOO) on the Martian Moons eXploration (MMX) spacecraft
- Project Manager (PM) of the wide-angle multi-band camera (OROCHI) on MMX
- Co-I of the infrared camera (IR1) on the Venus Climate Orbiter (Akatsuki)

Former Position(s):

- PI of the hydrogen Lyman-Alpha Imaging Camera (LAICA) on the PROCYON spacecraft

Education: PhD (Science), The University of Tokyo, 2007

Services in National and/or International Committees (last ones):

- Member of Mars landing Research Group in JAXA (2016-)
- Chair of UV Spectrograph for Exoplanet (UVSPEX) WG in JAXA (2017-)

Selected Publications:

S. Kameda, S. Ikezawa, M. Sato, M. Kuwabara, N. Osada, G. Murakami, K. Yoshioka, I. Yoshikawa, M. Taguchi, R. Funase, S. Sugita, Y. Miyoshi, M. Fujimoto. Ecliptic North-South Symmetry of Hydrogen Geocorona, Geophysical Research Letters 44, https://doi.org/10.1002/2017GL075915, 2017

S. Kameda, H. Suzuki, T. Takamatsu et al, Preflight Calibration Test Results for Optical Navigation Camera Telescope (ONC-T) Onboard the Hayabusa2 Spacecraft, Space Science Review, 208, Issue 1-4, pp 17-31, 2017

Cho, Y., Horiuchi, M., Shibasaki, K., **Kameda, S.**, Sugita, S, Quantitative potassium measurements with laser-induced breakdown spectroscopy using low-energy lasers: application to in situ K–Ar geochronology for planetary explorations. Applied Spectroscopy, DOI: 10.1177/0003702817701941, 2017.

Kameda, S., I. Yoshikawa, M. Kagitani, and S. Okano, Interplanetary dust distribution and temporal variability of Mercury's atmospheric Na, Geophys. Res. Lett., 36, L15201, doi:10.1029/2009GL039036, 2009.

Curriculum Vitae: LASERNA, Javier
Affiliation: Universidad de Malaga, LaserLab, Malaga, Spain

Role in the project: Team Member

Current position: Professor of Analytical Chemistry
Former Position(s): PhD at DLR Berlin, Germany, about LIBS for salt and ice detection on Mars. Post-Doc at Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France, on ChemCam LIBS.
Education: PhD in chemistry from University of Malaga 1980

Honors:

- associate editor of Applied Spectroscopy, and member of the advisory board of Spectrochimica Acta, Part B – Atomic Spectroscopy, Reviews in Analytical Chemistry, and the Open Journal of Analytical Chemistry
- member of the IUPAC Commission V.4 on Spectrochemical and other Optical Procedures for Analysis, from 1996 to 2001 and head of the Office for Technology Transfer of the University of Málaga, 1994 -1997.
- President of the Spanish Society for Applied Spectroscopy (SEA), 2001-2004 and of the Working Group in Spectrochemical Analysis of the Spanish Royal Society of Chemistry (RSEQ), 1998-2001.
- RSEQ National Award for Research in Analytical Chemistry in 2009 and SEA National Award for Research in Applied Spectroscopy in 2010.

Selected Publications:

Laserna, J. J. (1996). Modern techniques in Raman spectroscopy.

Romero, D., & Laserna, J. J. (1997). Multielemental chemical imaging using laser-induced breakdown spectrometry. *Analytical chemistry*, *69*(15), 2871-2876.

Vadillo, J. M., & Laserna, J. J. (2004). Laser-induced plasma spectrometry: truly a surface analytical tool. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *59*(2), 147-161.

Palanco, S., López-Moreno, C., & Laserna, J. J. (2006). Design, construction and assessment of a field-deployable laser-induced breakdown spectrometer for remote elemental sensing. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *61*(1), 88-95.

Lopez-Moreno, C., Palanco, S., Laserna, J. J., DeLucia Jr, F., Miziolek, A. W., Rose, J., ... & Whitehouse, A. I. (2006). Test of a stand-off laser-induced breakdown spectroscopy sensor for the detection of explosive residues on solid surfaces. *Journal of Analytical Atomic Spectrometry*, *21*(1), 55-60.

Moros, J., Lorenzo, J. A., Lucena, P., Miguel Tobaria, L., & Laserna, J. J. (2010). Simultaneous Raman Spectroscopy− Laser-Induced Breakdown Spectroscopy for instant standoff analysis of explosives using a mobile integrated sensor platform. *Analytical chemistry*, *82*(4), 1389-1400.

Fortes, F. J., Moros, J., Lucena, P., Cabalín, L. M., & Laserna, J. J. (2012). Laser-induced breakdown spectroscopy. *Analytical chemistry*, *85*(2), 640-669.

Purohit, P., Fortes, F. J., & Laserna, J. J. (2017). Spectral Identification in the Attogram Regime through Laser-Induced Emission of Single Optically Trapped Nanoparticles in Air. *Angewandte Chemie*, *129*(45), 14366-14370.

Moros, J., ElFaham, M., & Laserna, J. J. (2018). Dual-Spectroscopy Platform for the Surveillance of Mars Mineralogy using a Decisions Fusion Architecture on Simultaneous LIBS-Raman Data. *Analytical chemistry*.

He is co-inventor of 6 patents held by the University of Malaga and has published over 250 papers plus 5 books and book chapters.

NAME, First Name: LING, Zongcheng

Affiliation: School of Space Science and Physics, Shandong University, Weihai, Shandong Province, China

Role in the project: Team member

Current positions:
- Principal Investigator of LIBS instrument in Shandong University
- Principal Investigator of Planetary Science Group in Shandong University

Education: PhD, Shandong University, 2008; topic: Planetary Science
Services in National and/or International Committees:
- Committee Member of GeoRaman International Science Advisory Committee (GRISAC)

Honors:
- Top Ten advances in astronomical observations and technologies of China in 2015, 2016

Selected Publications:

Ling Z., Wang A. (2010) A systematic spectroscopic study of eight hydrous ferric sulfates relevant to Mars. Icarus, 209(2): 422-433.

Ling Z., Wang A., Jolliff B. (2011) Mineralogy and Geochemistry of four Lunar Soils by Laser-Raman Study. Icarus, 211, 101-113.

Ling Z., Jolliff B., Wang A., et al. (2015) Correlated compositional and mineralogical investigations at the Chang'e-3 landing site. Nature communications, 6: ncomms9880.

Ling Z., Wang A. (2015) Spatial distributions of secondary minerals in the Martian meteorite MIL 03346,168 determined by Raman spectroscopic imaging, J. Geophys. Res., 120(6): 1141-1159.

Wu Z., Wang A., Ling Z. (2016) Spectroscopic study of perchlorates and other oxygen chlorides in a Martian environmental chamber. Earth and Planetary Science Letters, 452: 123-132.

Liu C., Ling Z., Cao F., et al. (2017) Comparative Raman and visible near-infrared spectroscopic studies of jarosite endmember mixtures and solid solutions relevant to Mars. Journal of Raman Spectroscopy, 48(11): 1676-1684.

He is author or co-author of over 40 peer-reviewed publications in the areas of planetary sciences and instrumentation.

Curriculum Vitae: MAURICE Sylvestre
Planètes, Environnements et Plasmas Spatiaux, Institute of Research in Astrophysics and Planetology, Toulouse, France

Role in the project: Team member

Current positions:
- Co-PI of the ChemCam remote LIBS instrument on the *Curiosity* Mars rover
- Co-PI of the SuperCam remote LIBS instrument for the NASA Mars 2020 rover
- Co-PI for the Venus Elemental and Mineralogical Camera (VEMCam LIBS) instrument development for the NASA New Frontiers Program
- co-PI of the RLS experiment onboard the ESA ExoMars 2020 mission to Mars
- co-I of the plasma instrument package for the Cassini space mission
- co-I of the Japanese SELENE mission
- co-I of the ESA SMART-1 mission
- co-I of the Indian Chandrayaan-1 mission.
- collaborator of the NASA Lunar Prospector mission,
- Collaborator of the NASA Mars Odyssey mission
- Collaborator of the NASA Messenger mission around Mercury.

Education: PhD, U. of Paris, 1994; topic: Planetology
1990 degree of aerospace engineering from Sup-Aéro, Toulouse, France

Services in National and/or International Committees:
- S. Maurice has several national commitments, among which as the chairman of the CNES Solar System group (2004 – 2014).

Honors:
- NASA Group Achievement Award, for the ChemCam team
- Chevalier de la Légion d'Honneur

Selected Publications:
Wiens R.C., et al. (2012) The ChemCam Instruments on the Mars Science Laboratory (MSL) Rover: Body Unit and Combined System Performance. Spa. Sci. Rev. 170, 167-227, doi 10.1007/S11214-012-9902-4.

Wiens, R. C., Maurice, S., Lasue, J., Forni, O., Anderson, R. B., Clegg, S., ... & Deflores, L. (2013). Pre-flight calibration and initial data processing for the ChemCam laser-induced breakdown spectroscopy instrument on the Mars Science Laboratory rover. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *82*, 1-27.

Maurice, S., Wiens, R. C., Saccoccio, M., Barraclough, B., Gasnault, O., Forni, O., ... & Bernardin, J. (2012). The ChemCam instrument suite on the Mars Science Laboratory (MSL) rover: Science objectives and mast unit description. *Space Science Reviews*, *170*(1-4), 95-166.

He is author or co-author of over 120 peer-reviewed publications in the areas of space, planetary sciences and instrumentation.

NAME, First Name: REN Xin

Affiliation: National Astronomical Observatories, Chinese Academy of Sciences

Role in the project: Team member

Current positions:
- Deputy Chief designer of ground research application system of China first mission to Mars
- One of the technical leaders of ground research application system of china deep space exploration mission for optical payload data processing(including LIBS)

Education: PhD, National Astronomical Observatories, Chinese Academy of Sciences, 2011; topic: Planetary Science

Honors:
- National Defense Science and Technology Progress Award, third prize, 2015

Selected Publications:

Ren, X., Li, C. L., Liu, J. J., Wang, F. F., Yang, J. F., Liu, E. H., ... & Zhao, R. J. (2014). A method and results of color calibration for the Chang'e-3 terrain camera and panoramic camera. Research in Astronomy and Astrophysics, 14(12), 1557.

Wang, W. R., Ren, X., Wang, F. F., Liu, J. J., & Li, C. L. (2015). Terrain reconstruction from Chang'e-3 PCAM images. Research in Astronomy and Astrophysics, 15(7), 1057.

Yan, W., Liu, J., Ren, X., Wang, F., Wang, W., & Li, C. (2015). Orbit optimization of Chang'E-2 by global adjustment using images of the moon. Advances in Space Research, 56(11), 2389-2401.

Ren, X., Liu, J. J., Wang, F. F., Wang, W. R., Mu, L. L., & Li, H. H. (2014, April). A New lunar global topographic map products from Chang'E-2 Stereo Camera Image Data. In European Planetary Science Congress (Vol. 9).

NAME, First Name: SCHRÖDER, Susanne

Affiliation: Deutsches Zentrum für Luft- und Raumfahrt (DLR), Berlin, Germany

Role in the project: Team Member

Current position: Team leader junior research group "LIBS and Raman spectroscopy for Solar System Exploration" at DLR
Former Position(s): PhD at DLR Berlin, Germany, about LIBS for salt and ice detection on Mars. Post-Doc at Institut de Recherche en Astrophysique et Planétologie (IRAP), Toulouse, France, on ChemCam LIBS.

Education: PhD in physics 2012

Honors: CNES Post-Doc grant. 3 NASA Group Achievement Awards (ChemCam, MSL). Junior research group grant.

Selected Publications:

D.S. Vogt, K. Rammelkamp, **S. Schröder,** H.-W. Hübers, "Molecular emission in laser-induced breakdown spectroscopy: An investigation of its suitability for chlorine quantification on Mars", Icarus Vol. 302, 470-482, 2018.

S. Schröder, P.-Y. Meslin, O. Gasnault, S. Maurice, A. Cousin, R. Wiens, M.D. Dyar, N. Mangold, M. Nachon, S. Clegg, J.R. Johnson, J. Lasue, S. Le Mouelic, A. Ollila, P. Pinet, W. Rapin, and the MSL Science Team, "Hydrogen detection with ChemCam at Gale Crater", Icarus Vol. 249, Special Issue: First Year of MSL, 43-61, 2015.

P.-Y. Meslin, O. Gasnault, O. Forni, **S. Schröder**, S. Clegg, G. Berger, J. Lasue, A. Cousin, S. Le Mouélic, S. Maurice, N. Mangold, C. Fabre, R. Wiens, B. Ehlmann, P. Pinet, N. Lanza, R. Anderson, D. Archer, D. Bish, D. Blake, D. Blaney, N. Bridges, B. Clark, G. Dromart, M.D. Dyar, M. Fisk, W. Goetz, K. Herkenhoff, J.-L. Lacour, Y. Langevin, L. Leshin, E. Lewin, M. Madsen, H. Newsom, A. Ollila, E. Rampe, V. Sautter, J.-B. Sirven, L. d'Uston, D. Vaniman, and the MSL Science Team, "Soil diversity and hydration as observed by ChemCam at Gale crater, Mars.", Science 341, No. 6153, 1238670, 2013.

S. Schröder, S. G. Pavlov, E. K. Jessberger, I. Rauschenbach, and H.-W. Hübers, "Detection and identification of salts and frozen salt solutions combining laser-induced breakdown spectroscopy and multivariate analysis methods: A study for future Martian exploration.", Icarus Vol. 223, Issue 1, 61-73, 2013. S. G. Pavlov, S. Schröder, I. Rauschenbach, E. K. Jessberger, H.-W. Hübers, "Low-energy laser induced breakdown spectroscopy for in-situ space missions to solar system bodies without atmospheres.", Planetary and Space Science Vol. 71, Issue 1, 57-63, 2012.

S. G. Pavlov, E. K. Jessberger, H.-W. Hübers, **S. Schröder**, I. Rauschenbach, S. Florek, J. Neumann, H. Henkel, and S. Klinkner, "Miniaturized laser-induced plasma spectrometry for planetary in situ analysis – The case for Jupiter's moon Europa.", Adv. Space Res. 48, 764-778, 2011.

NAME, First Name: SOBRON, Pablo

Affiliation: SETI Institute / NASA Astrobiology Institute / Impossible Sensing

Role in the project: Team Member

Current position: Research Scientist
2011-2013 Natural Sciences and Engineering Research Council of Canada (NSERC) Postdoctoral Fellowship
2011-2013 Canadian Space Agency Visiting Fellow
2009-2011 Washington University in St. Louis Postdoctoral Fellow

Education:
2008 Ph.D. Europaeus – Physics and Vibrational Spectroscopy and Materials of Technological Interest - University of Valladolid, Spain.

Services in National and/or International Committees (last ones):
NASA Mars 2020 Science Team Member (2014+)
NASA MSL Science Team Member (2011-2013)
ExoMars Science Team Member (2008+)
GeoRaman International Advisory Science Committee (2014+).

Honors:
2014 NASA Group Achievement Award: Planetary Lake Lander Project
2013 NASA Group Achievement Award – MSL Science Office Development and Operations

Selected Publications:
Sobron P., Wang A., Mayer D. P., Bentz J., Kong F., and Zheng M. (2018) DLT Saline Playa in a Hyperarid Region of Tibet Plateau-III: Correlated multi-scale surface mineralogy and geochemistry survey. Astrobiology, In Press.
Lefebvre C., Catalá-Espí A., Sobron P., Koujelev A., and Léveillé R. (2016) Depth-resolved chemical mapping of rock coatings using Laser-Induced Breakdown Spectroscopy: Implications for geochemical investigations on Mars. Planetary and Space Science, 126: 24-33.
Sobron P., Lefebvre C., Leveille R., Koujelev A., Haltigin T., Du H., Wang A., Cabrol N., Zacny K., and Craft J. (2013) Geochemical profile of a layered outcrop in the Atacama analogue using laser-induced breakdown spectroscopy: Implications for Curiosity investigations in Gale. Geophysical Research Letters, 40: 1965-1970.
Sobron P., Wang A., and Sobron F. (2012) Extraction of compositional and hydration information of sulfates from laser-induced plasma spectra recorded under Mars atmospheric conditions — Implications for ChemCam investigations on Curiosity rover. Spectrochimica Acta Part B: Atomic Spectroscopy, 68: 1-16.

NAME, First Name: WAN Xiong

Affiliation Shanghai Institute of Technical Physics (SITP), Chinese Academy of Sciences (CAS)

Role in the project: Team Member

Chief scientist for qualitative and quantitative analysis of China's LIBS payload of HX-1 exploration project. He will share the relevant calibration databases and targets with the ISSI colleagues.

Current position:

Professor of SITP, CAS

Former Position(s):

Professor of Nanchang Hangkong University

Education:

2001–2005	Ph.D. in Test Technology and Instrumentation, Nanjing University of Aeronautics and Astronautics, China
1999–2002	M.S. in Test Technology and Instrumentation, Nanchang Institute of Aeronautical Technology, China
1987–1991	B.S. in Precision Instruments, Jiao Tong University, Shanghai, China

Services in National and/or International Committees (last ones):

Member of SPIE and SAS

Honors:

- Personal Research Award, Nanchang Hangkong University, 2006
- The third award of Chinese Aeronautical Society, 2009.
- The third prize of Jiangxi Natural Science Award, 2010.
- The first prize of Research Award of Universities in Jiangxi Province, 2010.
- The first prize of Shanghai Technology Progress Award, 2014

Selected Publications:

(1) X.Wan*, TT.Zhang, PX.Liu, Determination of calcium content in human body with laser-induced breakdown spectroscopy, Basic &Clinical Pharmacology &Toxicology, Vol. 120 (Suppl. 1) : 3-4, 2016.

(2) X.Wan*, P. Wang, Analysis of heavy metals in organisms based on an optimized quantitative LIBS, Optik 126 (2015) 1930–1934.

(3) X.Wan*, P. Wang, Remote quantitative analysis of minerals based on multispectral line-calibrated laser-induced breakdown spectroscopy (LIBS), **Applied Spectroscopy**, Vol. 68, No.10: 1132-1136, 2014.10.

(4) X.Wan*, R. Shu, G.H. Huang, Effects of rocket engines on laser during lunar landing, **Physics Letters A** 377(38): 2598–2603, 2013.11.

(5) X. Wan*, Zhimin Zhang, Qi Chen, Three Dimensional Radiation Thermometer Combining Near-Infrared Passband Thermometry with Optical Fiber Bundle Tomography, **Europhysics Letters**, 103(5): 50005-p1-5, 2013.9.

(6) X.Wan*, W. Xiao, Z. Zhang, "Emission Spectral Tomography With Optical Fiber Bundle," **IEEE/OSA Journal of Lightwave Technology**, Vol.30(2): 242-246, 2012.2.

(7) X.Wan*, Jianglin Yi, Zhimin Zhang, Wenhui Xiao and Lei Liu, Lagrange interpolation reprojection-revising reconstruction with incomplete data in optical computed tomography, **Optical Engineering**, Vol.49, No.8, 087001. 1-7, 2010.8.

Appendix 3 : List of team members' contact information

1. J. Lasue (jlasue@irap.omp.eu) Observatoire Midi-Pyrenees - Universite Paul Sabatier, Institut de Recherche en Astrophysique et Planetologie, 9 avenue du Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, Office: J-046, Tel: +33 (0)5 61 55 66 72
2. R. Wiens (LANL, USA, ChemCam and SuperCam PI, rwiens@lanl.gov)
3. S. Clegg (LANL, USA, LIBS specialist, ChemCam and SuperCam, sclegg@lanl.gov)
4. A. Cousin (agnes.cousin@irap.omp.eu) Observatoire Midi-Pyrenees - Universite Paul Sabatier, Institut de Recherche en Astrophysique et Planetologie, 9 avenue du Colonel Roche, BP 44346, 31028 Toulouse Cedex 4
5. S. Kameda (LIBS for MMX, Rikkyo University, Japan, kameda@stp.isas.jaxa.jp)
6. J. Laserna (Universita de Malaga, Laser Laboratory, Spain, laserna@uma.es)
7. S. Maurice (Sylvestre.Maurice@irap.omp.eu) Observatoire Midi-Pyrenees - Universite Paul Sabatier, Institut de Recherche en Astrophysique et Planetologie, 9 avenue du Colonel Roche, BP 44346, 31028 Toulouse Cedex 4
8. X. Ren (National Astronomical Observatories, Chinese Academy of Sciences, renx@nao.cas.cn)
9. S. Schroeder (DLR, Germany, LIBS specialist, Susanne.Schroder@irap.omp.eu)
10. P. Sobron (SETI Institute, NASA Astrobiology Institute, psobron@seti.org)
11. X. Wan (Shanghai Institute of Technical Physics (SITP), Chinese Academy of Sciences (CAS), wanxiong@mail.sitp.ac.cn)
12. Z. Ling (Shandong University, China, zcling@sdu.edu.cn)