The SuperCam Instrument onboard Perseverance: Overview of efforts compiled for Mars X conference. A. Cousin[1], R.C. Wiens[2], S. Clegg[3], O. Gasnault[1], R. Anderson[4], S. Bernard[5], P. Beck[6], O. Beyssac[5], A. Broz[2], G. Caravaca[1], B. Chide[1], E. Clavé[7], L. Coloma,[8] J. Comellas[9], S. Connell[2], E. Dehouck[10], O. Forni[1], M. Gillier[11], J. Johnson[12], H. Kalucha[13], M. Loche[1], J.M. Madariaga[8], H. Manelski[2], N. Mangold[14], M. Mann[15], J.A. Manrique[16], S. Maurice[1], T. McConnochie[17], R.T. Newell[3], A. Ollila[3], I. Poblacion[8], P. Pilleri[1], F. Poulet[18], C. Quantin-Nataf[10], S. Robinson[3], C. Royer[19], S. Schröder[7], A. Udry[20], U. Wolf[3], A. Zastrow[3] and the SUPERCAM team, [1]IRAP, Toulouse, France (agnes.cousin@irap.omp.eu), [2]Purdue Univ., [3]LANL. [4]USGS, [5]IMPMC, [6]IPAG, [7]DLR, [8]Univ. of Basque Country, [9]Univ. Hawaii, [10]Univ. Lyon, [11]ISAE, [12]JHU/APL, [13]California Institute of Technology, [14]LPG, [15]CNES, [16]UVA, [17]SSI, [18]IAS, [19]LATMOS, [20]Univ. Las Vegas.

Introduction: The Perseverance rover landed at Jezero crater on February 18th, 2021. The choice of this landing site for the Mars2020 mission was motivated by its geological significance and the potential insights into Mars' past habitability and search for past life. Indeed, Jezero crater once contained a lake, with a very well preserved delta on the west, making it an ideal location to search for signs of ancient microbial life. The Perseverance rover has four main objectives: 1. Search for traces of past microbial life 2. Characterize Mars's climate and geology in the landing site 3. Collect samples for later return to Earth 4.Test technologies for future missions.

Perseverance is equipped with seven scientific instruments, including the SuperCam suite [1,2]. SuperCam combines several remote-sensing techniques in order to study both the Martian surface and its atmosphere: 1. the LIBS (Laser-Induced Breakdown Spectroscopy) technique gives access to the chemical composition of the targets (up to 15m). All major elements are quantified (Si, Ti, Al, Fe, Mg, Ca, Na, K [3]) and the quantification of some minor elements is under progress [4]; 2. The Raman spectroscopy enables the identification of major mineral phases via the use of a 532nm pulsed laser, for Raman shifts between 150 and >4000cm^{-1}; 3. The VISIR spectroscopy gives access to the mineralogy, via the reflection of sunlight to access the frequency of molecule bond vibrations of the targets. The VIS range covers the 379-464nm and 535-855nm range, and the IRS part is comprised in the 1.3-2.6 microns range using an Acousto-Optic Tunable Filter spectrometer [5]; 4. The Remote Micro Imager (RMI) uses a CMOS camera of 2048x2048 pixels, with an angular size of 10 microradians and a resolution of 50 microradians; 5. The microphone records air pressure fluctuations from 20 Hz to 12.5 or 50 KHz, at sampling rates of 25 or 100 KHz, respectively.

As of sol 1128, Perseverance has driven a total of 26.7 Km, and explored the crater floor during the first 1.5 years before beginning its exploration of the delta front and delta top. Currently, the rover is exploring the Margin Unit since sol 910.

SuperCam performs remote observations around the rover allowing a large number of acquisitions. Indeed, when analyzing a target to get access to its chemistry and/or mineralogy, several point analyses are performed when doing LIBS, Raman and/or VISIR, in order to assess its homogeneity and to improve the overall precision. Typically ten points per target are performed. SuperCam can inform the choice of samples to collect for Earth return from these characterizations. Moreover, the atmospheric studies require recurrent observations, either at similar times (passive sky) or at different times of the day (microphone) to investigate potential seasonal effects or atmospheric processes.

SuperCam statistics: Up to sol 1100, SuperCam has analyzed a total of 992 geological targets. Each geological target is covered by a series of observations in a dedicated command sequence.The laser has primarily been used to collect LIBS observations: 203 000 laser shots were used for the LIBS; whereas 148 000 were used for Raman, and 14 000 for the fluorescence. Raman analyses are more efficient when crystals in the target sample are large and and relatively pure, which has been seen infrequently in Jezero crater. This is why the LIBS is the main laser technique to be used.

A total of 855 activities on Mars targets use either the VIS or the IRS technique, for the first time in-situ. This represents a total of 8358 IRS data points for mineralogical investigations. Concerning atmospheric studies done recurrently, 95 passive sky observations have been performed.

The RMI is used to record context images for each analyzed target (with at least 2 images, in order to build a mosaic of it) together with some long distance investigations (RMI only, targets up to infinity). A total of 4270 RMI have been acquired so far.

Finally, the microphone is systematically combined with the LIBS activities to gain insight into the target's physical properties. In addition, it has been used for 498 standalone microphone activities for atmospheric study, representing 22 hours of recording.

The SuperCam data can be found on the Planetary Data System [6], in a variety of formats. The raw spectra as well as the calibrated ones (LIBS, Raman, TRLS, VISIR), raw RMI and acoustic recordings with their calibrated counter parts. The quantification from LIBS data is also available, along with VISIR data ratioed to a calibration target. Minerals possibly identified along the traverse from Raman and TRLS dare are also listed in a table.

SuperCam efforts All these measurements have led to more than fifty publications since the landing. This literature addresses the main objectives of the Mars2020 mission: the context of the landing site [RMI only 7], the igneous history of the crater floor [multi technique 8-10], investigation of the alteration processes that could have occurred [multi technique 11-12], and about the current environment [microphone 13-17].

Geological context and selection of the samples After the crater floor campaign, igneous primary minerals are encountered along the traverse in the delta in igneous boulders that have been transported [18,19], and also in the delta bedrocks, for which their origin is not clear yet. However the comparison of these igneous minerals from the delta and margin unit with those encountered in the crater floor and in Mars meteorites could help constrain their origin [20]. [21] investigates the composition of the carbonates found in the margin unit by comparing them to the primary minerals composition in order to better constrain their formation processes. Some light-toned float rocks have been encountered along the traverse since the landing. Most of them are particularly enriched in Al2O3 and their mineralogical composition is modeled using VISIR data [22] but also using LIBS [23]. They also show an elevated Ni content, which could constrain their formation process [24]. Some studies of terrestrial analogs are in progress [25]. One particular float rock is Si-rich and could correspond to Opal [26]. With its small footprint, SuperCam is also used to investigate specific features, such as coating [27] and concretions [28]. SuperCam's IRS capability provides it a great opportunity to compare in situ to orbital observations from the same unit, with different instruments and length scales [29]. Multi-instrument studies are also performed, such as the combination of all the instruments on abraded patches to better understand the origin of the carbonates in these samples [30]. VISIR data from SuperCam and MastCam-Z on the abraded patches and drill fines are also associated to document spectral features related to primary and secondary minerals [31]. Finally, the remote micro-imager of SuperCam is particularly useful for geomorphologic and sedimentary studies. The images acquired in the delta illuminate the fluvial and deltaic stratigraphy throughout the delta to better constrain the fluvial inputs in the crater, and therefore provide insights into the history of Jezero lake [32]. The first in situ sequence stratigraphic analysis on Mars has been realized on the Kodiak butte [33]. The chemostratigraphy and mineralogy of the western fan revealed a complex aqueous history and alteration conditions in the delta [34]. The preservation or organic materials is also investigated via Raman data on the organic calibration target onboard the rover [35].

Atmospheric science. Since landing, the SuperCam microphone has led to several discoveries [12-16], with a review of the acoustic results presented in [36]. One of the latest results describes the high frequency turbulence on Mars [37]. Passive sky observations are used to investigate the variability of molecular oxygen in the martian atmosphere [38]. Atmospheric observations have also contributed to the discovery of a Martian aurora from the SuperCam and MastCam-Z instruments [39]. This is the first time such phenomena are observed *in situ*. Simulation efforts are underway, including a model simulating the propagation of the sound in the lower part of the atmosphere [40].

Laboratory and modeling efforts. Several laboratory investigations are ongoing in support of Mars observations. Some of these studies include specific elemental calibrations, such as P or F [41, 42]. Other studies aim at improving the sensibility of SuperCam to detect serpentine, which is a mineral with a wide variety of compositions [43]. Some laboratory data explore the Raman signal on shocked carbonates, which have been observed in some Mars meteorites [44]. Several laboratory simulation experiments are under progress. Some aim at understanding the formation pathways of the Na perchlorates [45] observed with SuperCam [46], and others aim at constraining the redox and past aqueous environment during the carbonate formations [47]. [48] presents a spectral unmixing method to identify some minor and trace elemental lines present in the LIBS data. A broader database of LIBS spectra is being assembled in order to better quantify LIBS data, which is ongoing [49]. The LIBS plasma dynamics on these database data is also investigated to verify the quality of our data [50]. Several modeling efforts are developed for the VISIR data to better constrain the mineralogical assemblages present in the targets [51-53] and to help the comparison with other rover techniques.

References: [1] Maurice et al., Space Sci. Rev. 217 (2021) [2] Wiens et al., Space Sci. Rev. 217 (2021) [3] Anderson et al., Spec. Chem. Acta B 188 (2022) [4] Gabriel et al., LPSC 2024 [5] Fouchet et al., Space Science Rev (2022) [6] https://pds-geciences.wustl.edu/missions/mars2020/supercam.htm. [7] Mangold et al., Science, (2021) [8] Wiens et al., Science Advances (2022) [9] Beyssac et al., JGR (2023) [10] Udry et al., JGR (2022) [11] Mandon et al., JGR (2022) [12] Clavé et al., JGR (2022) [13] Maurice et al., Nature (2022) [14] Murdoch et al., Nat. Com. (2022) [15] Chide et al., JGR (2022) [16] Stott et al., JGR (2022) [17] Lorenz et al., PSS (2023) [18] Beyssac et al., LPSC 2024 (2024) [19] Dehouck et al., LPSC (2024) [20] Udry et al., this meeting (tm) [21] Clavé et al., tm [22] Royer et al., tm[23] Madariaga et al., tm [24] Forni et al., tm [25] Broz et al., tm [26] Beck et al., LPSC 2024 [27] Ollila et al., tm [28] Kalucha et al., tm [29] Quantin-Nataf et al., tm [30] Connell et al., tm [31] Johnson et al., tm [32] Caravaca et al., tm [33] Mangold et al., tm [34] Dehouck et al., tm [35] Bernard et al., tm [36] Chide et al., tm [37] Maurice et al., tm [38] McConnochie et al., tm [39] Knutsen et al., tm [40] Gillier et al., tm [41] Wolf et al., tm [42] Wolf et al., tm [43] Comellas et al., tm [44] Coloma et al., tm [45] Poblacion et al., tm [46] Meslin et al., LPSC 2022 [47] Loche et al., tm [48] Schröder et al, tm [49] Anderson et al., tm [50] Manelski et al., tm [51] Poulet et al., tm [52] Zastrow et al., tm [53] Royer et al., LPSC 2024.