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Mars acoustics: a playlist of surface-atmosphere interactions recorded at Jezero crater. Baptiste Chide¹, Sylvestre Maurice¹, Ralph Lorenz², David Mimoun³, Xavier Jacob⁴, Naomi Murdoch³, Alexander Stott³, Martin Gillier³, Franck Montmessin⁵, Jérémie Lasue¹, Nina Lanza⁶, Susanne Schröder⁷, Fabian Seel⁷, Tanguy Bertrand⁸, Agnès Cousin¹, Roger C. Wiens⁹. ¹IRAP, Toulouse, France, (baptiste.chide@irap.omp.eu), ²Johns Hopkins APL, Laurel, MD, USA, ³ISAE-SUPAERO, Toulouse, France, ⁴IMFT, Toulouse, France, ⁵LATMOS, Guyancourt, France, ⁶LANL, Los Alamos, NM, USA, ⁷DLR, Berlin, Germany, ⁸LESIA, Meudon, France, ⁹Purdue University, West Lafayette, IN, USA.

Introduction. Before the landing of Perseverance (18 February 2021), no pressure fluctuations had ever been monitored on Mars at a frequency higher than 20 Hz, namely, in the acoustic domain [1]. Theoretical models predicted a muted atmosphere where high-frequency sounds are drastically attenuated by the large intrinsic absorption of CO₂, while low frequencies are dominated by the rumble of the wind.

NASA's Perseverance rover landed in Jezero crater carrying the two first microphones operating on the surface of Mars: the SuperCam microphone [2, 3], positioned on top of the rover's articulating mast and the EDL microphone [4] fixed on the body of the rover. Working flawlessly since then, they provide, for the first time, the Mars soundscape in the audible range and beyond, from 20 Hz to 50 kHz [5]. Detected sounds originate from three main sources: the atmosphere (turbulence, wind), the shock-waves generated by the SuperCam laser ablating rocks, and mission-induced artificial sounds such as the signal generated by the high-speed rotating blades of the Ingenuity helicopter.

After two Martian years, the Perseverance playlist features more than 24 hours of Martian sounds. In addition to highlighting the unique sound propagation properties of the low-pressure CO₂-dominated Mars atmosphere, it provides an unprecedented short

timescale characterization of the wind, temperature fluctuations, and the turbulence dissipative regime. This presentation shows how the characterization of the local acoustic environment around Perseverance provides new clues to study the surface-atmosphere interactions in Jezero crater.

Winds and dust lifting. Passive sensing of the Mars atmosphere, revealed previously unobserved pressure variations down to 1,000 times smaller scales than ever observed before, highlighting the transition to the turbulent dissipative regime where eddy energy is transferred to small scales and later dissipated [5,6]. Wind-induced acoustic signals can be used to infer the wind speed using machine learning model [7] and it exhibits rapid fluctuations highlighting episodic gusts on the 1–10 s scales with temporarily high speeds that could not be observed with hot-film anemometers.

These gusts and turbulent behaviors are of critical importance to understand the ongoing surface changes on Mars, such as dust lifting and saltation processes. In particular, the SuperCam microphone was able to characterize the rapid wind structure and the vortex grain loading through the sound recording of a dust devil that passed directly over the rover [8]. It is a unique case to analyze the wind conditions under which energetic grain motion occurs.

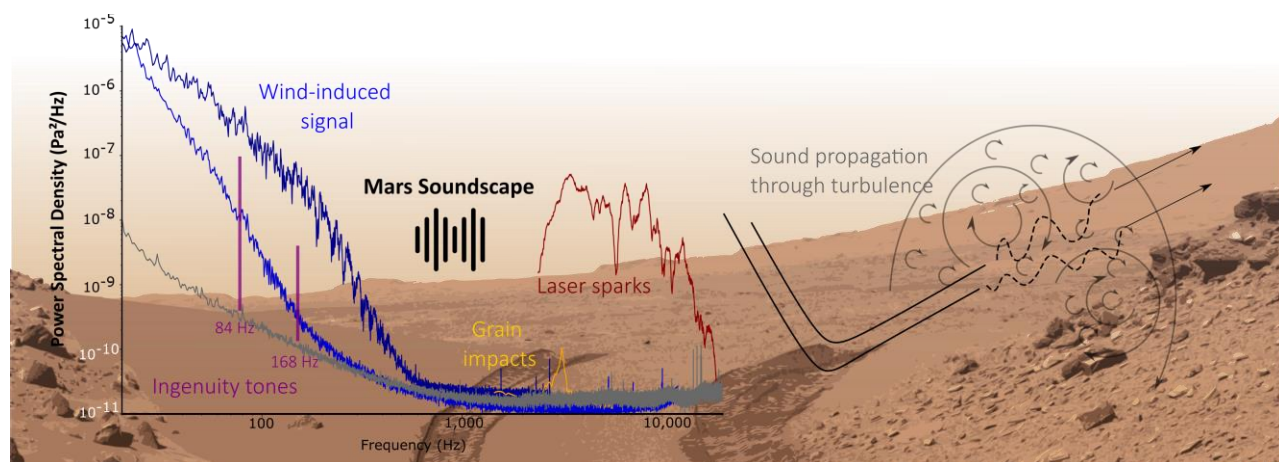


Figure 1. Variety of sounds recorded by the SuperCam microphone on Mars

High frequency turbulence. One of the particular interest of the SuperCam microphone is that it is coupled with its own reproducible sound source, the blast waves generated by the SuperCam laser-induced plasma expansion. As the spark-induced N-waves propagate, they are scattered from the multiple local heterogeneities of the turbulent atmosphere. Therefore, large and random fluctuations of sound travel time and intensity develop as the waves cross the medium. The fluctuations are studied within the mathematical formalism of the propagation of spherical acoustic waves through turbulence to infer statistical properties of the Mars atmospheric fluctuation field. The measurement of the speed of sound provides a new method on another planet to retrieve the atmospheric temperature independently from traditional thermocouple sensors. It sheds light on large temperature fluctuations over a very short timescale, $\pm 5\text{K/s}$ on average and up to 10K/s [9]. Moreover, sound amplitude fluctuation data help estimate the distribution of turbulent eddies. It was found that the turbulence field on Mars can be described by a von Karman spectrum with a shallower slope than the Kolmogorov cascade, associate with an outer scale of turbulence of about 10^{-2}m around noon [10]. These observations are to be refined to take into account wind fluctuations and ground-blocking of buoyantly produced turbulent velocity fluctuations [11].

Altogether, these acoustic measurements on Mars represent a new asset to probe the near-surface atmosphere, a key layer for the surface-atmosphere exchanges on Mars [12].

Sound propagation properties. Owing to the unique combination of a microphone and two sound sources, the Ingenuity helicopter and the SuperCam laser-induced sparks, the Perseverance rover payload is used to extract sound propagation properties of the Mars' atmosphere. Transmitted sound intensity varies by a factor of 1.8 from a constant source due to the seasonal cycle of pressure and temperature that significantly modifies the acoustic impedance, *i.e.* the coupling between the atmosphere and the microphone [13]. Finally, data have shown that the evolution of the Ingenuity tones and laser spark amplitudes with distance is consistent with the existing sound absorption models [14], which is a key parameter for numerical simulations applied to geophysical experiments on CO_2 -rich atmospheres. From these two sound sources, two distinct values for the speed of sound were observed: the value for Ingenuity, at frequencies below 240 Hz is about 10 m/s slower than that above 240 Hz for laser sparks which allows us to

better understand how vibrational relaxation in CO_2 molecules affects Mars's acoustics in the audible range [5]

Recording artificial sounds. In addition to being employed for the investigation of sound propagation, the acoustic signature of sources enables the characterization of the sources themselves.

A support to SuperCam laser-induced breakdown spectroscopy investigations. Each laser spark recorded by the microphone finds its origin in the expansion of a Supercam laser-induced plasma, whose physical and chemical properties are influence by the coupling between the laser beam and the targeted rock surface [15]. Consequently, it has been shown that the laser-induced acoustic signal can be used to infer the hardness of rocks at Jezero crater [16]. This is a new information to be compared with the chemistry data; initial results show a good correlation with the alteration degree of igneous rocks studied in the crater floor [17, 18].

Ingenuity helicopter flights. Distinct acoustic signatures of the helicopter were recorded on the 4th, 5th, 6th, and 8th flights. They are around 84 Hz and (occasionally) at 168 Hz, at the blade crossing frequency and its first harmonic [19]. Doppler shift of the 84 Hz signal can be measured and is consistent with the trajectory measured with Ingenuity's navigation camera. acoustic measurements are a useful diagnostic of the rotor flight characteristics at least to distances of $\sim 100\text{m}$, which may be relevant in supporting future helicopter mission on Mars, including 'fetch' helicopters supporting the Mars Sample Return operations or understudy Mars Science Helicopter.

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