# Acoustic wave propagation in the near-surface Martian atmosphere

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## *Abstract*

*The present internship aims to investigate the impact of atmospheric absorption and turbulence on the propagation of sound in the Martian atmosphere using three-dimensional numerical simulations of the parabolic approximation of the wave equation. The study will examine the attenuation of acoustic waves due to vibrational relaxation in $CO_2$ and the effects of temperature fluctuations and turbulence on wave scattering. Furthermore, a comparative analysis between Mars and Earth will highlight key differences in acoustic propagation due to variations in atmospheric composition and dynamics.*

## Project detailed description

**Context & motivation.** Sound propagation in extraterrestrial atmospheres is an emerging and rapidly advancing research field. Acoustics serves as a powerful method for characterizing planetary atmospheres by providing insights into their composition, temperature, winds, density, and pressure, as well as potential information on planetary interiors.
As part of NASA's Mars 2020 mission, the Perseverance rover landed in Jezero Crater on February 18, 2021, equipped with the SuperCam instrument (cf. Figure 1), which includes a microphone capable of recording sounds in the audible range (20 Hz - 20 kHz). This device has enabled the first direct acoustic measurements on another planet, offering new opportunities for studying sound propagation in extraterrestrial environments.

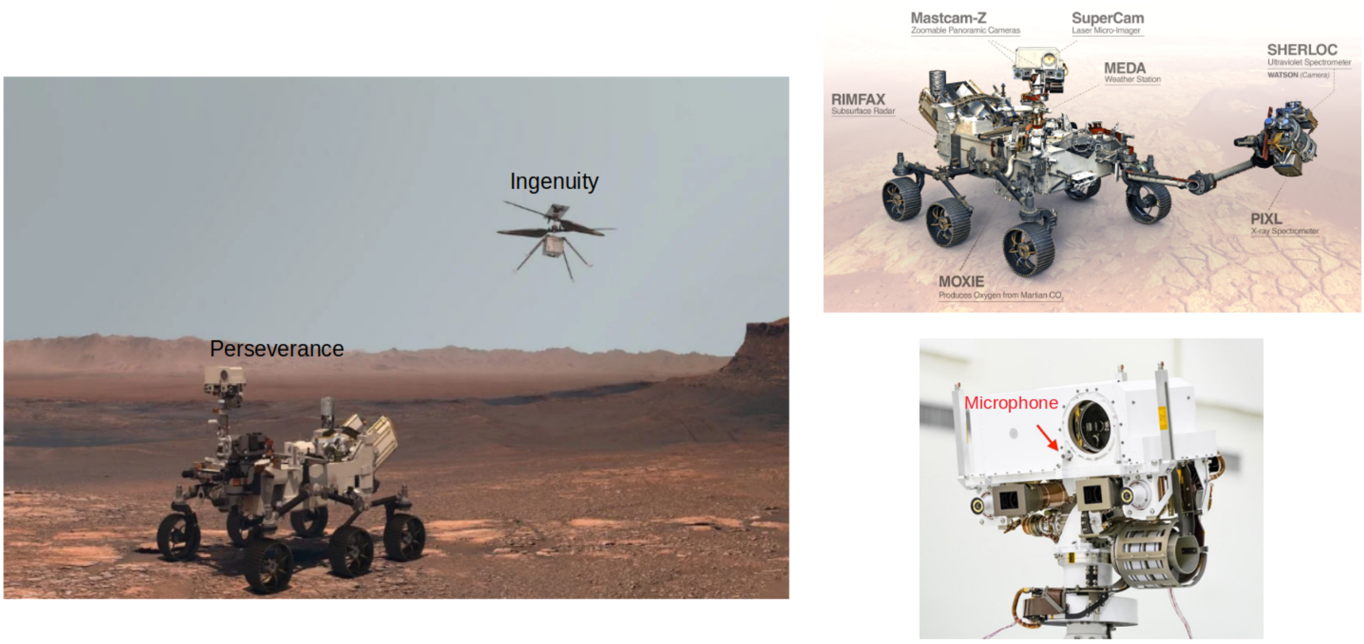


Figure 1: *Perseverance*, *Ingenuity*, and the *SuperCam* instrument

Alongside Perseverance's ground-based acoustic experiments, the Ingenuity helicopter was deployed (cf. Figure 1), completing 72 flights with a total flight time of 128 minutes and covering 17 km. The SuperCam microphone recorded the noise generated during several flights, identifying distinct acoustic signatures at 84 Hz and 168 Hz, corresponding to the blade-crossing frequency and its first harmonic. These recordings provide valuable data on acoustic wave propagation in Mars' atmosphere, particularly on absorption due to vibrational relaxation, which is more pronounced on Mars than on Earth because of its $CO_2$-rich atmosphere. Additionally, Perseverance conducted another acoustic experiment using the SuperCam microphone to capture spherical acoustic waves generated by laser-induced plasma sparks. As these waves propagate through Mars's turbulent atmosphere, they experience random fluctuations in travel time and intensity. Analyzing these variations provides insight into the statistical properties of Martian atmospheric turbulence.
Mars' unique atmospheric conditions make it a valuable natural laboratory for studying acoustic waves in extraterrestrial environments. Although initial studies have characterized key effects, further numerical and theoretical investigations are necessary to refine existing models and improve our understanding of sound propagation on Mars. More broadly, advancing our understanding of acoustic wave propagation on Mars can provide a foundation for studying acoustics in other extraterrestrial atmospheres and contribute to the development of acoustic-based measurement tools for future planetary exploration missions, including those to Titan and Venus, both scheduled for the 2030s.

**Objectives, methodology, and expected outcomes.** The present internship aims to study acoustic wave propagation on Mars, with a particular focus on the effects of atmospheric absorption and turbulence. The research will involve three-dimensional numerical simulations based on the parabolic approximation of the wave equation. Key aspects of the study include the attenuation of acoustic waves due to vibrational relaxation in carbon dioxide and the impact of temperature and wind fluctuations on wave scattering. In addition, a comparative analysis will be conducted to identify differences in acoustic propagation between Earth and Mars.
The research will be conducted in the following stages.

1. Literature review of acoustic wave propagation in planetary atmospheres and the parabolic equation.
2. Development of a solver for the numerical resolution of the parabolic approximation of the 3-D wave equation.
3. Examination of the effects of atmospheric composition, temperature gradients, and turbulence on sound waves, with a comparative study between Mars and Earth.

This internship is expected to produce the following key results.

1. A numerical solver of the parabolic approximation of the 3-D wave equation.
2. Insights into the impact of Mars' atmospheric composition, temperature variations, and turbulence on acoustic waves.

The study of acoustic wave propagation in extraterrestrial atmospheres offers valuable insights into planetary environments. The first direct acoustic measurements on Mars, recorded by the Perseverance rover's SuperCam microphone, have provided new data on sound behavior in a $CO_2$-rich, low-density atmosphere. Through 3-D numerical simulations, this internship will help refine theoretical models of acoustic wave propagation under Martian conditions. The work may also serve as a foundation for a potential Ph.D. project.

## References

1. Maurice *et al.*, Nature, 605, 2022
2. Lorenz *et al.*, Planetary and Space Science, 230, 2023
3. Chide *et al.*, J. Acoust. Soc. Am., 155, 2024
4. Gillier *et al.*, JGR Planets, 129, e2024JE008469, 2024
5. Gillier *et al.*, JGR Planets, 129, e2023JE008257, 2024