Guest editorial: Acoustic and related waves in extraterrestrial environments

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I. INTRODUCTION

Recent years have seen a resurgence of acoustic sensing in planetary exploration, complementing the prevailing electromagnetic techniques. For outreach purposes mostly, some attention was paid to converting electromagnetic sensor pickup into audio playback signals. Such examples are the effects of Saturn's lightning[1] or bow wave[2] on the Cassini spacecraft or those of pulsar emissions on Earth-based sensors.[3]

Lately the potential of genuine acoustical information has been increasing steadily.[4] Sound waves carry information on the properties of the propagation medium, which we can access: from the ratio of the stiffness to the density in the sound speed, to the interplay of chemistry and relaxation processes in the frequency-dependent absorption and phase speed. Sound and vibration interact with matter intimately, in a way that complements—and in many ways exceeds—the electromagnetic interactions conventionally used on probes. These interactions occur in the atmospheres of Venus, Titan, and Mars, in the under-ice oceans of Europa, and in the lakes of Titan, and can reach to the cores of planets. They can be seen in the acoustic sensor that monitors the gentle fall of dust onto the surface of a moon, the seismic waves detected by Apollo missions to the Moon,[5,6] in the oscillations of gas giants[7] and stars[8,9] (that can indicate the presence of orbiting planets[10]), and in the oscillations of vast dust clouds, as density fluctuations[11,12] which, on very large scales, have heralded the eventual formation of stars and planets. Furthermore, our own visceral interactions with sound in daily life provide opportunities for outreach and education from studies of acoustics in extraterrestrial environments.

Acoustic exploration in planetary science started by making rudimentary measurements in challenging environment, one of the first attempts being a passive instrument accompanying the final Venera landers on Venus.[13,14] The microphones, looking for evidence of thunder, were only able to measure sounds generated aerodynamically by air flowing past the lander. Capacitive foil microphones had actually been used before during some Apollo Moon landers, to determine the statistics of dust raised by the landing impacts.[15] Berg *et al.*[16] describe an efficient technique to determine the velocities of dust particles and micrometeorites that relies on analyzing acoustic waveforms produced by particle impacts on impact plate microphones. The technique was successfully used on Apollo missions to the Moon[16] and, more recently, on the Rosetta mission[17] to the Comet 67 P/Churyumov-Gerasimenko. A somewhat larger collision, that of Comet Shoemaker-Levy 9 with Jupiter, added significantly to the body of knowledge about the range of mechanical waves that can exist in the atmosphere of Jupiter[18,19] and the ice giants Uranus[20] and Neptune.[21]

We have never recorded the natural soundscape of another world. There are rare data from microphones, but it is likely that the pressure fluctuations that are attributed to "the sound of wind" are aerodynamic pressure fluctuations on the surface of the microphone (i.e., they are not acoustic, and do not propagate to distance at the local speed of sound). Use of multiple microphones to distinguish such fluctuations from acoustic signals has not been employed to date, and the windscreens commonly used to shield microphones from this on Earth would present challenges for extra-terrestrial use (e.g., in decontamination to prevent the possibility of introducing microbes from Earth to other worlds). Acoustic instrumentation has tended to be based on common usage on Earth, rather than being specifically designed for an extra-terrestrial environment. In 1999, a substantially "off-the-shelf" microphone[22] was flown onboard the ill-fated Mars Polar Lander, which crashed during descent. The Mars Descent Imager system of the 2008 Phoenix lander had a microphone, designed to record descent sounds as well as any post-landing acoustic event. However, the plans to turn the microphone on were scrapped in order to avoid a technical problem that might have been potentially dangerous to the mission.[23] The Mars2020 rover will carry a custom-designed microphone to record ambient sounds.[24]

Perhaps the most carefully thought-out acoustics suite deployed to date was that carried by the Huygens probe[25] that landed on Titan in January of 2005. Beside a microphone for recording the ambient sounds of Huygens' descent in Titan's thick atmosphere, the Huygens Atmospheric Structure Instrument had an active ultrasonic sensor that measured the speed of sound over the last 12 km before the landing. Moreover, analysis of ultrasonic signal attenuation obtained immediately after landing seems to indicate the presence of volatile gases such as ethane, acetylene, and carbon dioxide.[26] The Surface Science Package had an acoustic transmitter-receiver configuration commonly used to assess distance to ground (e.g., in depth sounders). This Sound Detection and Ranging system, called the Acoustic Properties Instrument–Sounder, was used to assess

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the distance to and characteristics of the landing zone.[27,28] Whilst measurements of the atmospheric speed of sound,[29] and estimates of the distance to the ground, were made, no passive time history records were obtained of genuine acoustical signals (spectra of what was probably non-acoustic aerodynamic noise were transmitted bath to Earth, but without the means of recovering the time series).

Given the mixed success in deploying microphones on planetary probes, the discrepancy between the relatively low financial investment in acoustic equipment for planetary probes versus the potential that acoustic signals have shown on Earth (in air, sea, rock, and tissue) for telling us about the environment, and the failure to record the natural soundscape (i.e., genuine acoustic signals) from another world, a range of studies were set up to plan missions and test the opportunities and ambiguities that might face such missions. These included investigating the lakes and methanefall soundscapes of Titan,[30,31] and probing the ice seas of Europa[32–34] or atmospheric fluctuations in Venus.[35] They included looking at the way the extreme density contrasts that occur in transitioning from Earth's atmosphere to those of other worlds might introduce unexpected effects or errors, if we base our mission planning on instrument performance,[36,37] calibration, or procedures[38] that are familiar from Earth-based practices. In order to design, deploy, and interpret acoustic systems for anemometry,[39] or infer atmospheric chemistry from the local sound speed,[40,41] predict the sound of thunder on Titan,[42] or for public engagement predict how voices or musical instruments might sound on other worlds,[43–45] we need to know the speed of sound[46,47] and absorption.[48,49,55]

The goal of this Special Issue is to emphasize the role acoustics can play in the exploration of wave motions in Solar System environments and—possibly, in the near future, as long-range sensing evolves—in exoplanetary systems. The papers contained herein are meant to present a portion of the wide spectrum of applicability of acoustic and other wave-related phenomena to the study of alien environments.

A first class of papers describes acoustic techniques that may be developed, tailored specifically for the conditions met in extraterrestrial environments. Ainslie and Leighton[50] discuss how the sonar equation would have to be approached if it were to be applied to atmospheres, surface seas, and/or inner oceans of worlds like Titan, Venus, Europa, and Enceladus. Banfield *et al.*[51] describe the practical implementation—and challenges—of designing three-axis ultrasonic anemometers for measuring Martian wind velocity fields. The main challenge, posed by the low density of Mars' atmosphere, can be overcome by careful experimental design utilizing capacitive transducers combined with pulse compression techniques. Corsaro *et al.*[52] describe the development of an acoustic instrument for measuring properties of micrometeorites and other dust particles in space.

Another class of contributions addresses models of acoustic propagation in terrestrial atmospheres. Thus, Petculescu[53] focuses on the intrinsic absorption and dispersion of sound in the low and middle atmospheres of Mars and Venus, also touching on planet-specific sensor design challenges such as acoustic sensing in the tenuous Martian atmosphere or the choice of high-temperature piezoelectric materials for ultrasonic transduction on Venus. Lognonné *et al.*[54] present models for atmosphere-mediated coupling of Rayleigh waves for the upper atmospheres of Mars and Venus, offering a comparison with existing models for Earth.

An important aspect of the effort to expand acoustical research in planetary science lies in the ability to convey the information to general audiences. The contribution by Leighton *et al.*[55] present an acoustic system developed specifically for a planetarium, which is able to simulate alien "soundscapes" by placing the listener in virtual environments perturbed by the sounds of thunder, dust devils, or cryo-volcanoes. Using vocal tract modeling, the system also enables visitors to hear their voices altered interactively by the atmospheres of Mars, Venus, and Titan.

In discussing the roles of "sound in space" in public engagement, instrument design, atmospheric propagation modeling, and as a testbed to allow us to test and question our current practices and models, the papers in this issue illustrate some of the challenges that face us if we are to make the most of the opportunities for using acoustics in planetary exploration.

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