THE SOUND OF MUSIC AND VOICES IN SPACE
PART 1: THEORY

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Introduction

While probes to other planets have carried an impressive array of sensors for imaging and chemical analysis, no probe has ever listened to the soundscape of an alien world.[1–3] With a small number of exceptions, planetary science missions have been deaf. The most successful acoustic measurements were made by the European Space Agency's 2005 *Huygens* probe to Titan, but although this probe was spectacularly successful in measuring the atmospheric sound speed and estimating the range to the ground using an acoustic signal that the probe itself emitted,[4–7] we still have no measurements of sounds generated by alien worlds. Although microphones have been built for Mars,[8] the *Mars Polar Lander* was lost during descent on 3 December 1999, and the *Phoenix* probe microphone was not activated (because the Mars Descent Imager system to which it belonged was deactivated for fear of tripping a critical landing system).[9] Instead of measuring acoustic signals that had propagated to the microphone from a distance, aerodynamic pressure fluctuations on the microphone (caused by wind on the surface of Venus in the case of the 1982 Russian *Venera* 13 and 14 probes,[10,11] and turbulence during the parachute descent in the case of *Huygens*) masked the soundscape on these Venus and Titan missions. Given the lack of such data from these earlier missions, some early enthusiasts for acoustics in the space community are now skeptical as to whether it will ever have a useful role. However basing such an assessment on past performance presupposes that the sensor systems have been optimized for the environment in question.

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Space programs work within challenging mission constraints (e.g., in terms of sensor weight, power consumption, bandwidth, ruggedness). Acoustic systems can match these constraints well.[1–3] Cutting edge acoustical capability goes far beyond what is commercially available, yet even the latter holds potential solutions to problems that limited past missions. For example, the aerodynamic pressure fluctuations which prevented measurement of the soundscape by *Venera* and *Huygens* might have been mitigated by the deployment of appropriate microphone windshields (extraterrestrial versions of those used by journalists to report from stormy locations) or the use of two or more synchronized microphones to separate the real acoustical signals from aerodynamic pressure fluctuations[12–15] At the cutting edge, appropriate models of the generation and propagation of sounds are today being inverted to estimate key environmental parameters (such as rainfall at sea, tornado detection, animal location, icecap erosion, crack formation in aircraft wings, erosion in hydroelectric turbines,[16–20] in addition to the established techniques for seismic and global test ban monitoring). Given the vast expense involved in sending an acoustic sensor to another world, it is vital that that sensor be properly designed for the alien environment, and that the data it detects be sufficiently free of artifacts so that it can be interpreted correctly. Detailed modeling of acoustic characteristics of alien worlds is therefore vital to the design of instrumentation, the planning of the acoustical components of the missions, and the correct interpretation of the data. If the astronaut from the future is walking down a Martian hillside, looking downwards, can we design microphones to warn him of the fall of a rock dislodged behind him? How well can sound be used to confirm the opening of vanes out of camera sight on unmanned probes, or undertake diagnostics of motors, pumps and drills? What gain, bandwidth, sensitivity and self-noise are appropriate for microphones in the atmospheres of Mars, Titan, Venus, and the planets, or hydrophones in the lakes and oceans of Titan, Europa and Enceladus? Would we be able to recognize sounds as coming from "dust devils" on Mars,[21] "waterfalls" on Titan,[22] ice cracking on Europa,[23–26] or lightning on Venus? Could not novelists, film, and documentary makers attempt to portray the soundscape with the same integrity they apply to the visual depiction of other worlds?

For acousticians, the measurement of the soundscape is probably the most interesting role for extraterrestrial acoustics, as the sources of sound are themselves part of the alien world. However acoustics has three other roles in space exploration.[1] First, measurement of the propagation of signals generated by the probe itself can be used for range-finding, anemometry, or key gas properties through the measurement of atmospheric sound speed and dissipation.[27–34] Related studies include the active seismic experiments[35] of Apollo 14, 16 and 17. Second, perturbations in other signals (EM) can be interpreted by appealing to acoustic models of fluctuations in their source or the propagation medium. Examples include modal acoustic waves in planets[36] and stars,[37,38] and acoustic perturbations in planetary rings, comets and noctilucent clouds.[39–44] Third, signals that were never acoustic (such as radio waves generated by Jovian lightning) can, for the purposes of providing a subjective impression, be converted into an audio record for human listeners.[45]

The fourth aspect, however, of detecting the audio-frequency soundscape of another world, remains elusive. We have been tantalizingly close to providing this, with the wind noise data from Venus and Titan mentioned above, and the passive seismic geophone data from the Apollo missions.[46–51] Optimized instrument design is required to ensure that attempts to measure the soundscapes of other worlds are not discouraged by lack of success in early missions. In addition to the physical hostility of the environment, instrumentation must be designed to match the acoustical issues of the alien world. Some of these we will have solved for terrestrial instrumentation (such as the wind noise effect discussed above), but some will be particular to a given world (such as the high absorption on Mars[52] or the fluid loading effects on Venus[53]). However it is vital that those missions are equipped with sensors that are designed with knowledge not only of the environment they will encounter, but also of the likely soundscapes they will be expected to measure. To design sensors, and interpret soundscapes, we need tools to predict how sounds will be generated, and how they will travel significant distances from source to receiver, on alien worlds. The remainder of this article uses the examples of music and speech to illustrate how we might begin to provide such tools.

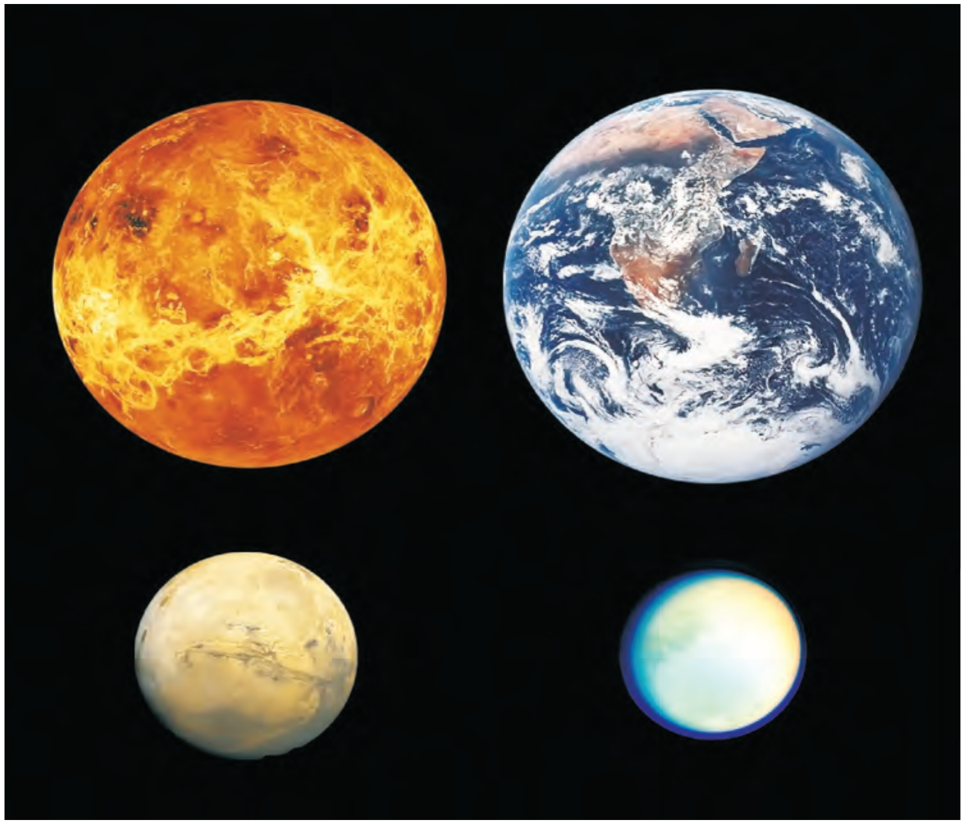

Fig. 1. Composite, with planet size to scale, of Venus (top left), Earth (top right), Mars (bottom left) and Titan (bottom right). An atmospheric halo is visible around Titan. Images making up this composite are courtesy of NASA/nasaimages.org, Lunar and Planetary Institute and Jet Propulsion Laboratory.

Bach and planetary acoustics

Predictive modeling is key to the effective planning, design and interpretation of extraterrestrial acoustic missions. Models of the generation and propagation of sound on other worlds are used in the sound files accompanying this paper that demonstrate how organ music and speech would sound on Venus, Mars and Titan. These two sounds are chosen because the instruments involved provide extreme examples of the different ways in which extraterrestrial worlds affect the range of terrestrial instruments (and other sound sources). Although this exercise may seem fanciful, in that it will probably be many decades before an astronaut on Mars, waiting for the return trip, constructs an instrument outside the living area, the great complexity of musical sound sources and the discernment with which we assess their performance means that they provide an ideal demonstration of the factors (material, geometrical and dynamic) which need to be considered when any stiff, light, structure vibrates on another world. Such structures are not restricted to musical instruments—they might range from atmospheric dirigible-like vehicles to sensors on planetary probes, such as those that respond with high sensitivity to changes in the inertia or stiffness associated with vibrating surfaces as, for example, species accumulate upon an oscillating plate.[54] The reason for studying speech and music is that they are familiar sound sources which display a wealth of effects from an alien world's atmosphere, in comparison to Earth's. On Venus, for example, the pitch of a flue organ pipe will increase because it is susceptible to changes in sound speed but not fluid loading, while the note of a harmonica reed will fall since it has exactly the opposite sensitivities. The voice is susceptible to both, giving perceived changes in both the pitch and size of the speaker. Understanding of how such familiar structures can give such different responses to an alien world may help us identify the sources from the soundscape of another world, and design sensors appropriate for the expected sounds.

Three extraterrestrial worlds—Mars, Venus, and Titan—are studied and compared with Earth (Fig. 1). Its low tem-

Fig. 2. Picture from the surface of Titan, taken by ESA's Huygens probe. The light-toned rock below and left of center is only about 15 centimeters across and lies 85 centimeters away (Credit: ESA, NASA, Descent Imager/Spectral Radiometer Team, Jet Propulsion Laboratory).

perature (-178°C) means that, despite its small size, Saturn's moon Titan has a thick atmosphere. At ground level, the atmospheric pressure on Titan is 1.5 bar, and the sound speed is only 62% that of Earth[52] (Fig. 2). It is assumed, for the purpose of this exercise, that the organ contains only flue pipes, so that the note of a given organ pipe scales linearly with sound speed. Under this assumption, Bach's Toccata and Fugue in D minor (293.66 Hz) played on Titan will automatically be transposed down to the key of ~F# minor (185 Hz). The atmospheres of Mars (Fig. 3) and Venus (Fig. 4) are both dominated by CO_2 and N_2. However, their surface temperatures are extremely different, leading to ground-level sound speeds that are, respectively, 70% and 120% of the sound speed on Earth.[52] Thus Mars' thin and cold (-46 °C) atmosphere transposes Bach's Toccata down to ~G# minor (207.65 Hz), while Venus' dense and hot (457 °C) atmosphere transposes it up to ~F minor (349.23 Hz)—nearly an octave above Titan's rendition at F# (185 Hz).[55]

The acoustic absorption, on the other hand, affects the propagation of sound in a different manner on the four worlds.[52] Thus Titan's nitrogen-based atmosphere is less lossy than Earth's, so that the music can carry to similar distances (although, as on Earth, variations due to season and latitude, atmospheric stratification and any wind could become important, especially at very long distance propagation e.g., of infrasound). The CO_2 on Mars and Venus absorbs the sound far more than does Earth's air, such that on Mars the music at full volume is barely audible merely 10 meters from the organ (suggesting that the *Mars Polar Lander* and *Phoenix* microphones, had they been activated, would have had very limited range).

Figure 5 shows the transmission loss (TL) in dB as a function of frequency calculated based on geometrical spreading and acoustic absorption. Geometrical losses are assumed to be spherical for all these worlds and independent of frequency: at 10, 20, 50 and 100 m they contribute, respectively, 20, 26, 34 and 40 dB of the transmission loss (i.e., the bulk of the TL for Titan). Additional losses are contributed by atmospheric absorption—on Titan these losses are smaller than on Earth, while the carbon dioxide on Venus, and particularly Mars, produces very high absorption of sound. The assumed atmospheric pressures (p), temperatures (T) and composition for each world are as follows, allowing the atmospheric sound speed (c) to be calculated—Earth (77% N_2, 21% O_2, 1% H_2O; p = 1 bar, T = 22°C, c = 340 m/s); Titan (95% N_2, 5% CH_4; p =1.5 bar, T= -178°C, c = 210 m/s); Venus (96% CO_2, 3.5% N_2, trace SO_2; p= 90 bar, T = 457°C, c = 410 m/s); Mars (95% CO_2, 2.7% N_2, 1.6% Ar, 0.13% O_2 ; p = 0.007 bar, T = -46°C, c = 240 m/s), noting that the actual values (e.g., of temperature) can vary significantly with time and latitude.

While the attenuation of musical sounds with distance is similar for most instruments, the effects of the extraterrestri-

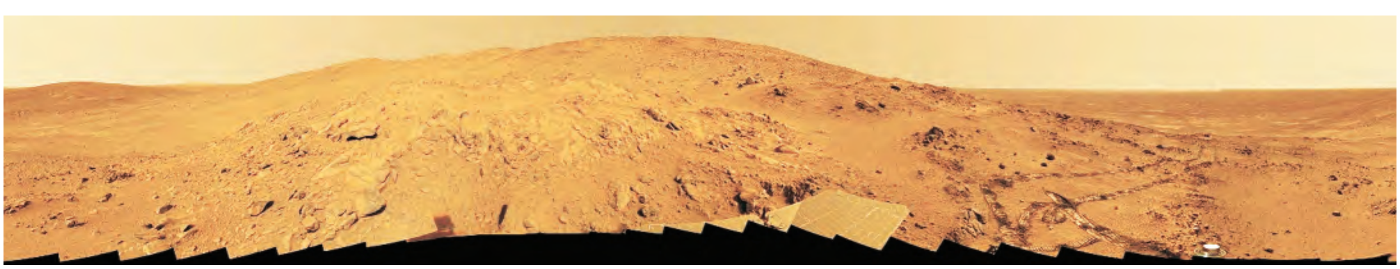

Fig. 3. A 360° panorama image of Mars, taken by NASA's Mars Exploration Rover Spirit from halfway up Husband Hill, the summit of which can be seen about 200 meters southward and about 45 meters higher (Credit: Jet Propulsion Laboratory).

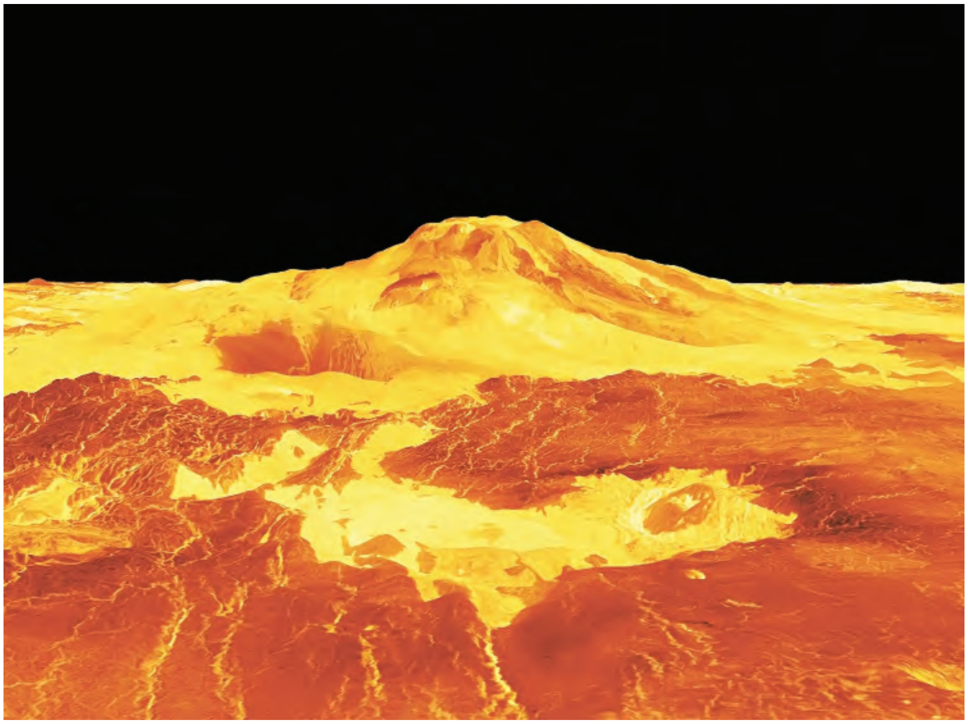

Fig. 4. Magellan synthetic aperture radar data is combined with radar altimetry to develop a computer generated three-dimensional perspective of the surface of Venus, showing the 5 km-tall volcano Maat Mons and the surrounding terrain. The viewpoint is located 634 kilometers north of Maat Mons at an elevation of 3 kilometers above the terrain. Lava flows extend for hundreds of kilometers across the fractured plains shown in the foreground, to the base of Maat Mons (simulated hues are based on color images recorded by the Soviet Venera 13 and 14 spacecraft) (Credit: Jet Propulsion Laboratory).

al atmospheres on the timbre and pitch are markedly different. We will assume that the instrument has been constructed to withstand the environmental conditions (the high temperatures and pressures at ground level on Venus posing a particular challenge). Electrical instruments will be relatively unaffected. Care was taken in the above illustration to specify that the organ was assumed to contain flue pipes only, so that the high sound speed on Venus would cause the pitch of the note to rise. However if the organ also contained reed pipes, fluid loading in Venus' atmosphere would cause the pitch of those pipes to decrease.[53] If an organ tuned on Earth were to be played with both reed and flue pipes on Venus, the result would be very different from the simple pitch-shift discussed above for the flue pipes, since the different types of pipes would experience a pitch shift in opposite directions. Furthermore the vibration frequency of the reed would no longer be matched to the resonances of its pipe. The effect of fluid loading is less on Titan and Mars (where the thin atmosphere might find it more difficult to make the reeds vibrate at all), such that there, the effect of sound speed would be the major consideration. However because on Venus a wealth of different physical phenomenon can affect the various mechanisms by which an instrument generates sound, shifting resonances in different directions on the same instrument, this planet is by far the most intriguing (especially when one considers that surface conditions will require the most ingenuity when it comes to the choice of materials).

The reason why Venus has such an effect is as follows. The frequency of a flue organ pipe will, to a first approximation, scale with the sound speed of the atmosphere (although there will be second order effects based on interactions with the pipe wall as the gas density increases). However the note of a reed organ pipe is primarily determined by the vibrational frequency of the lightly-damped reed (which is tuned to match the pipe frequency so that the pipe amplifies the note and provides timbre). In the dense atmosphere of Venus, the "added mass" associated with the displacement of atmosphere as the reed vibrates will reduce its natural frequency.[53] However the resonances of the pipe to which the reed is attached will increase. Hence a reed pipe tuned on Earth will find its resonances mismatched on Venus: for a given reed, the pipe length will need to increase if the resonances are to be brought back into correspondence.

The "added mass" associated with an alien atmosphere will tend to decrease the natural vibration frequencies of a structure if the atmosphere is denser than Earth's (as is the case on Venus, Titan, and the gas giants).[53] However Mars' thin atmosphere gives less "added mass" than Earth's, tending to increase vibrational resonance frequency.[53] Understanding such fluid/structure interaction is vital for predicting the performance and safety of structures in dense environments, particularly as there is no opportunity to drop-test these on Earth. This is particularly so for the lightweight structures used on probes, as is illustrated by the following example, where neglect of the fluid/structure interaction leads to an error of nearly 100% in the predicted frequency.[53]

The human voice responds to an alien atmosphere in a manner not dissimilar to the reed organ pipe. In contrast to the flue organ pipe note, the pitch of the human voice is largely unaffected by sound speed changes *per se*. Vowel pitch comes instead from the frequency of the mechanical vibration of a solid (the vocal folds). Changes to the gas in the pipe (the vocal tract, including the larynx, the pharynx, and the mouth and nasal cavities) affect only the resonances by which the listener gains an impression of the physical size of the speaker (e.g., a small child or a large adult). A reduction in the sound speed of the gas within that tract makes the speaker appear larger, while an increase in the sound speed makes the speaker appear smaller without altering the basic pitch of the voice (just as humans breathing helium sound smaller but, because the pitch is unaltered, they still sing in tune providing they were able to do so in air). However the "added mass" effect will change the frequency at which the vocal folds vibrate, preliminary calculations suggesting that fluid loading on Venus will drop the pitch by around half an octave

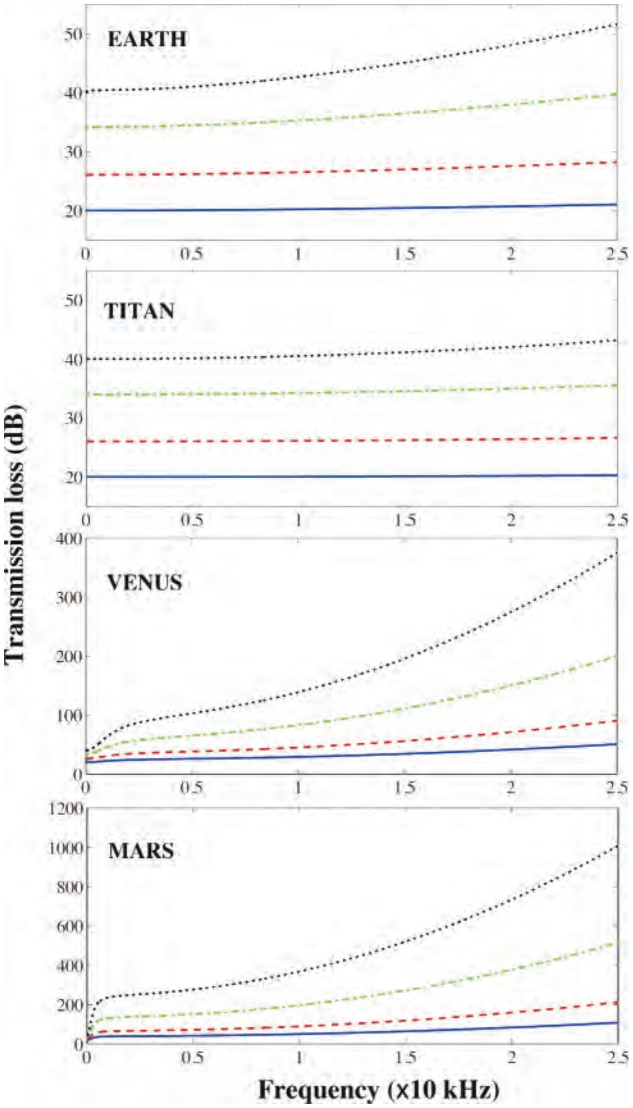

Fig. 5. The transmission loss as a function of frequency, for various propagation distances. It contains contributions to sound attenuation from geometrical spreading losses and atmospheric absorption. The reference distance in the transmission calculation is 1 m from the source. The colors (line types) indicate the different source-receiver distances: blue (solid) = 10 m; red (dash) = 20 m; green (dot-dash) = 50 m; black (dot) = 100 m.

for an adult, and nearly a full octave for a child. This is demonstrated in reference 53. That paper also shows that when considering the effect of fluid loading on other vibrating structures, the geometry and average density of the vibrating solid significantly affect the fluid loading. The density of the material matters, since the proportional significance of any given "added mass" is greater the less massive the original structure. Therefore, all other things being equal, a light carbon fiber structure (such as a Venusian drumskin) will be more significantly affected than a steel structure of otherwise identical vibrational properties and geometry. Furthermore, the fluid loading effect increases with the momentum of the gas set into motion by the vibrating structure. As a result, the fluid loading on the vocal folds is much greater in the vocal tract than it would be were the vocal folds to vibrate in free space, where geometric spreading would allow the gas vibration amplitude to fall off with distance from the vocal folds.

Taken in isolation, the fluid loading on a Venusian guitar string would be much less than the loading on a drum or pipe, since a vibrating wire sets much less gas into motion[53] (although of course, fluid loading on other structures, such as the body of the guitar, would also need to be considered).

The fact that Venus has the opposite effect with flue and reed pipes on the same instrument shows that the effect of an alien world on the sound generated by a given musical instrument therefore depends on the details of the mechanism by which that sound is generated. Additional degrees of freedom in the problem are available in the choice of materials used for construction and the extent to which adjustments are made to compensate for unwanted effects—while for example a wire can be tuned by altering its tension to counteract the effects of thermal expansion on Venus, the effect of Venus' temperature on the waves in the walls of a bell cannot be so easily counteracted. Indeed, the philosophy of wishing to counteract the alien effects is short-sighted, as the new sounds provide the artist with a palette of acoustic "colors" not available on Earth. Such considerations transpose the study of extraterrestrial music from science to art that might include planetarium experiences for the seeing and the visually impaired alike, more realistic soundscapes in science fiction movies, and compositions that use the sounds of other worlds.

Venus probably presents the most musically interesting of the three alien atmospheres studied, because the fluid loading effect is so great (it is almost negligible on Mars[53]) and shifts the frequencies in the opposite direction to the shift experienced by those resonances which depend on the atmospheric sound speed. A qualitative impression of the effect could be obtained by placing the mouthpiece from a larger member of an instrument family, into the body of a smaller member, since in general, the dense gas reduces the frequency of vibrating structure (by an amount depending on their geomtry and mass[53]), but increases the resonances of gas columns. So for example, given that the flue organ pipe was transposed up a minor third between Earth and Venus, one might suppose that the effect of Venus on a C-clarinet (a barely viable instrument even on Earth) can be understood (though not quantitatively reproduced) by placing its reed on the body of an E-flat clarinet (scaling the gas column resonance approximately correctly for the fact that Venus' ground level atmospheric sound speed is 120% that of Earth). However such sophistry is barely needed, since we know that clarinets are relatively robust to reed changes (the A and B-flat soprano instruments use the same mouthpiece). Indeed the authors were delighted to find that the A and B-flat soprano instruments still made recognizable tunes when played with the mouthpeice from the B-flat bass clarinet. Of course when we refer here to robustness to reed changes, we are not writing as connoisseurs of sound quality, since from that perspective many clarinetists would consider the fact that A and B-flat clarinets share mouthpieces to be a compromise. The bass B-flat reed on an A-clarinet plays a tune at the pitch of the A-clarinet, as expected, but the sound quality has been compromised. The dynamics of the mouthpiece are complicated,[56] and Venusian fluid loading should be mimicked by swapping the reed only, not the mouthpiece, since we simply wish to add inertia (and not volume) to the source, but this is not practical without significant instrument adjustment. However the context here of swapping mouthpieces is to provide a quick terrestrial illustration of the possibilities of subjective changes, rather than attempt an accurate simulation of the performance on Venus. Swapping mouthpieces does not properly explore how an alien world truly affects the interactions between the source of vibration and the many resonances that determine sound quality and power.

In other families, the mismatch between the mouthpiece and body may compromise the balance to a greater degree, even to the extent that it becomes unplayable. However the fact that the human voice is recognizable in a helium atmosphere suggests that some combinations may provide interesting results, and the importance of, say, fluid loading and the coupling of waves between gas and solid on Venus, opens up the opportunity to design instruments specifically for that world, instruments that make use of interactions that are less strong on Earth.

Combining the vibrating structure from one instrument with the body of a smaller one provides only a qualitative illustration of the effect of Venus. Quantitative calculation of the musical "colors" requires an understanding of the mechanisms by which the sound is generated. While a clarinet might appear to be very similar to a reed organ pipe, the predicted effect of an alien atmosphere is very different to that of the reed organ pipe, because in the clarinet the reed vibrates at a frequency much greater than that of the note being played, the pitch of the note being determined by the maximum acoustic impedance of the pipe.[57] In similar vein, percussion instruments of similar size such as a church bell and a kettledrum (or tympani) might seem similar at first glance, but the effect of an alien world on both would be very different (assuming they are constructed to survive). The vibrations from the massive bell depend primarily on the wave speeds in the metal, and so will be primarily affected by, say, temperature while being relatively insensitive to the density and sound speed in the gas (the gas will of course influence the sound detected at distance from all instruments). However the vibration of the kettledrum is the result of complex interactions between the membrane, the kettle and the gas, which affect the time responses and decays of the components, and shifts the frequencies of the dominant modes from the set of inharmonic modes that would be predicted for an ideal circular membrane in free space, to generate harmonic partials in the kettledrum. These frequency shifts are caused by the fluid loading of the gas in the drum (strongly dependent on gas density), the resonances of the gas within the drum (that will depend on the atmospheric sound speed), and the motion of the drum and membrane.[57,58]

Audio clips that show the effects of atmospheric filtering of the organ piece (assuming use of only flue pipes) can be heard in the online media files (throughout this article, the effect of alien worlds on source level has not been included). These files show how the atmosphere of Venus can raise the pitch of the organ pipe by a minor third but drops the pitch of a child's voice by nearly an octave, while making the speaker appear smaller (as though coming from a very short bass). The various classes of instruments will therefore be affected in different ways by alien environments. An orchestra on another planet could only in part correct for these changes by retuning or changing strings, or transposing music to another key, lengthening pipes and lightening reeds, etc. While such measures can, to a limited extent, compensate for pitch changes, the alien world will impart changes in timbre, such that the process of writing music becomes an activity that is specific for a given world.

The sound files

In September 2007, recordings were made of one of the authors (TGL, with verbal introductions by his children) playing the organ at St. Margaret's Church, East Wellow, Hampshire, UK (Fig. 6). These were processed using *Adobe® Audition®* to shift the pitch accordingly. Then filters were made to attenuate the sounds assuming absorption and an inverse square law for the acoustic intensity (spherical spreading). The specification of the organ (Fig. 7) is as follows (numbers conventionally indicate the length in feet of the lowest pipe of the stop): **Great Organ:** 8 ft Open Diapason; 8 ft Stopped Diapason; 8 ft Salicional; 4 ft Principal; 4 ft Harmonic Flute. **Swell Organ:** 8 ft Open Diapason; 8ft Lieblich Gedeckt; 8 ft Viol di Gamba; 8 ft Vox Angelica T.C.; 4 ft Gemshorn; 2 ft Flageolet; 8 ft Cornopean. **Pedal Organ:** 16 ft Bourdon; 8 ft Bass Flute extn.

The voices also were modified using STRAIGHT,[59] to

Fig. 6. St. Margaret's Church, East Wellow, Hampshire, United Kingdom is an early 13th Century building with earlier foundations. The grave of Florence Nightingale can be seen in the foreground.

compensate for sound speed changes within the vocal tract while properly amending the larynx vibration frequency for fluid loading. For interest, the calculated result if the fluid loading stage is neglected is also included in the media files.

The sound files are based on the assumption that they are recorded using a microphone that has the same performance characteristics on each planet as had the microphone used on Earth. Fluid loading and external conditions (pressure, temperature, etc.) would of course have to be taken into account in the design of the instrument, which includes use of the principles outlined in this paper (the same principles could of course be applied to examine to what extent the ear would be compromised, although we have some experience from this from tests of hearing underwater with and without an air bubble trapped in the ear).[60–67]

Furthermore, it is assumed that the organs have the same source level (intensity at the position of the organist). The actual source level consideration is more complicated than this, as such organ pipes are designed to speak when excited by a given pressure difference. Hence the source intensity considerations are not simply one of scaling but, as with many instruments, also incorporates thresholding effects.

The organ pipes are assumed to act as flue pipes and the end-corrections in the pipe are negligible. For the voice tracks, the same assumption carries through the processing to imply that the acoustic intensity of the voice at the microphone, 1 m from the speaker, is constant, which is unrealistic. As such, while the intensity of the music tracks can be compared with the calibration tone that is provided with the audio files, the intensity of the voice tracks cannot. While the predictions for the music tracks (involving as they do an inanimate organs and microphones) are meaningful with respect to the interpretation of future extraterrestrial signals in terms of source characteristics, and to the design of future microphones (for probes or helmets), the range of human factors involved in generating speech in alien environments means that the voice tracks are purely illustrative.

Conclusions

The purposes for which predictions have been made of the sounds of music are not grounded in the physical transposition of an Earth-tuned organ to another world: organs are constructed very much for the specific location they will occupy, and tuned appropriately (for example, the reed will be tuned to the pipe, and not vice versa). However the exercise quantitatively illustrated the range of both physical and subjective ways in which the alien world affects sound production and propagation. The modeling of sound on other worlds can inform the design of future acoustic sensors, and affirm our ability to predict, analyze, and interpret extraterrestrial acoustic phenomena accurately, whether that interpretation takes the form of the subjective recognition of thunder, a splashdown, wind or seismic activity, or whether it encompasses a full quantitative inversion.

With specific application to music, the effect of the alien world is dependent on the mechanism by which the sound is generated. The effect depends very much on the instrument and the environment—the example of flue and reed pipes being affected differently by the gas was given (not forgetting other factors: for example some reeds rely on gravity to supply the restoring force, while others do not). Indeed, changes of gas could be used to test the importance of components and their interactions in those instruments, where complex

Fig. 7. The organ.

interactions between a number of solid and gas components are thought to contribute to the overall sound (the example of tympani was given). While the effect of alien environments on terrestrial instruments might be thought of as a perturbation, in broader view it provides the musician with a new palette of sound, and the possibility of new instruments, with which to be creative.

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From left to right, Rhys, Timothy, and Rhiannon Leighton (2007)

Tim Leighton is Professor of Ultrasonics and Underwater Acoustics at the Institute of Sound and Vibration Research, University of Southampton, UK. He obtained M.A. and Ph.D. degrees in Natural Sciences (Physics) from the University of Cambridge, UK, and is a Fellow of the ASA, the Institute of Acoustics and the Institute of Physics. His research tends to cover various areas of sound in liquids (acoustical oceanography, biomedical ultrasonics, sonochemistry, etc.). However, his strong interest in physical acoustics, combined with his musical performance (he has performed oboe concertos with several orchestras), and interest in collecting and playing a range of instruments (string, woodwind, and percussion), has led to the current study.

From left to right, Luc, Andi, and Gabriela Petculescu.

Andi Petculescu is an Assistant Professor in the Department of Physics at the University of Louisiana at Lafayette. His current research includes acoustic studies in granular media and sound generation and propagation in planetary atmospheres. One of his goals is to convince the decision makers in planetary science space missions of the importance of acoustic sensing in extraterrestrial environments. It is for this reason that Andi has organized and chaired two special sessions on Acoustic Probes of Planetary Environments, at meetings of the Acoustical Society of America in Salt Lake City (June 2007) and Paris (June-July 2008). Andi and his wife (and fellow physical acoustician) Gabriela have a two-year old son, Luc.