Listening to X-ray Data

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Astronomy is thought of as a *visual* science, but astronomers have long since exceeded the wavelength range of the human eye. We find many ways to represent otherwise invisible data to our senses. If astronomical data can be represented in diverse ways, the audience for which the data are useful becomes more diverse, and our opportunities for conceptualizing the data expand as well.

At Glasgow University we have developed a tool for rendering space physics data non-visually, through sonification. Sonification can open up the space physics data collection to a new community of researchers now excluded from space physics research, including the visually impaired. In addition, the *sound* of many types of astronomical data allows for a richer intuitive understanding of it by everyone.

Sonification can benefit all students and researchers, allowing them to :

- analyze complex or rapidly/temporally changing data.
- explore large datasets (multi-dimensional datasets).
- intuitively explore datasets in the frequency domain.
- identify new phenomena that current display techniques miss.
- find hidden correlations and patterns masked in visual displays.
- monitor data while doing something else (background event-finding).

For instance, when searching solar data for bow shock and magnetopause crossings, we expect that distinctive signatures will be especially apparent above the background noise. These boundary signatures appear as characteristic changes in the whole spectrum. Other emissions appear as tones at distinctive frequencies or time-frequency spectra (such as electron plasma oscillations, magnetic noise bursts in the magnetosheath, and whistler mode emissions marking regions of currents).

The xSonify tool sonifies 1-dimensional data from text files and from CDAWeb heliophysics data holdings. xSonify is based on Java 1.5 with Java Sound, MIDI, JavaSpeech, WebStart and Web Services technology. xSonify features three different sonification modes (Pitch, Loudness, Rhythm) with various controls (Play, Stop, Loop, Speed, Time point). It includes capabilities for limited pre-processing of input data (Limits, Invert, Logarithm, Averaging). We will further enhance xSonify to handle all 1-dimensional (as well as multi-dimensional) data and add additional features. The source code is openly available at *http://xsonify.sourceforge.net* under the NASA Open Source Agreement (NOSA).

The non-visual representation of data (sonification), made possible through this tool began with NASA support, starting from the Space Physics Data Faciliy (SPDF) requirement to improve access to heliophysics data. This project will also meet the goals of contributing to the development of the science, technology, engineering, and mathematics (STEM) workforce (especially in under-served and under-represented communities) [NASA Education Outcome ED-1] and attract students to STEM disciplines [NASA Education Outcome ED-2].

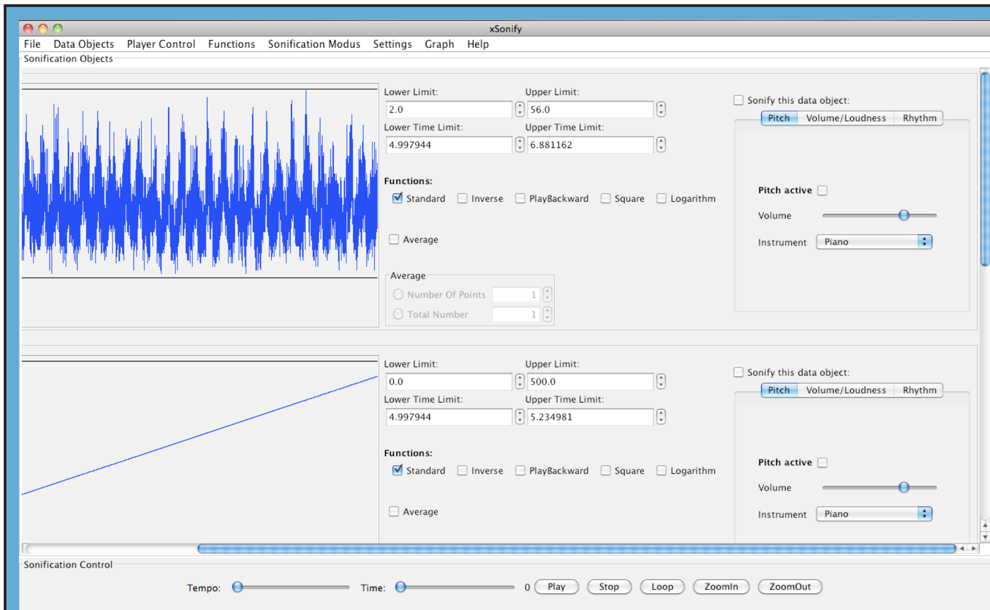

Fig. 1 - The xSonify user interface. Any 1-D data set (e.g., timeseries data, or a spectrum) can be imported into the application. The software will then sonify the data, converting the visible amplitudes (upper left), into auditory information that can be heard, augmenting the visual analysis of the data.

Sonified X-ray Data

EX Hydrae is a southern variable star classified as an eclipsing intermediate polar-type cataclysmic variable (CV) of the DQ Her type. As a binary with an orbital period of 98 minutes, EX Hya belongs to a small group of intermediate polars with ultra-short periods. The observed

Fig. 2 - First page of a 29 page musical score corresponding to the sonification of the FFT of the *Chandra* X-ray lightcurve of EX-Hya.

67-minute oscillation is believed to be the spin period of the white dwarf component. A long (~500 ks) *Chandra* observation of EX Hya was obtained with HETG and ACIS-S. We sonified the EX Hydra X-ray light curve in pitch mode, normalized to a musical scale, to analyze its frequency content. Temporal fluctuation information is portrayed as simultaneously sounded clusters of pitches. Phase, frequency and time variations as a function of pitch can be grouped and then extracted from the data. Persistent or intermittent features in the data may map to interesting physical parameters of the EX Hya system. Given the human ability to transform the disturbance reaching our ears from the space domain to the frequency domain, this step may be compared to decomposing the data into different simple modes of oscillation.

We listened to the FFT data, binned into segments of 10 min each. The frequency information was represented as musical notes readily familiar to the ear, and the spin period is easily recovered. A period search performed by extracting the harmonics showed several statistically significant periods in the range between 250 and 800 sec.

Perception Experiment

We recently completed perception experiments to investigate the effectiveness of sonification together with visual display for compare event detection in the data as compared to visual display only. A second aim of these experiments was to investigate whether sonification enhances data analysis. These rigorous laboratory experiments on attention control, and human-computer interaction (HCI), will help identify how combining sonification with visualization can enhance scientific data analysis. If new efficiencies or new capabilities are identified, our study seeks to understand how to build on these through training.

The perception experiments include empirical measurement of performance. Here, double-peaked radio-frequency spectra of water maser emission observed in the corners of active galactic nuclei were simulated by a pair of gaussians displayed on the screen, over which random noise was superimposed. Participants were presented simulated spectra and asked to identify the presence of a "signal" obscured by noise, at varying signal-to-noise ratios. Test volunteers experience astronomy data via audio cues, visual cues, both together, and also both cues with a sweep line. The volunteers responded to the cues using the keyboard, and their threshold for detection was estimated using an algorithm called QUEST (Quick Unbiased and Efficient Statistical Tree). We hope our results will bring a more diverse community into data analysis and will open up a multimodal approach to scientific data.

Acknowledgments

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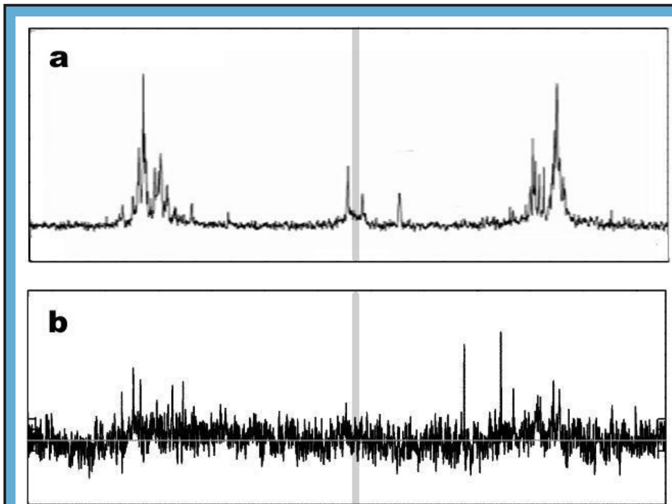

Fig. 3 - Our experiments simulated the double-peaked H_2O emission profiles from active galactic nuclei, here from (a) NGC 3393 and (b) NGC 591. A double gaussian was used to simulate the emission peaks, and random noise was added. The experiments measured the signal-to-noise threshold at which participants were able to reliably detect the "signal" in the presence of noise. The experiment compared response sensitivity in visual presentations, auditory presentations, and combined visual and auditory presentations to gauge the efficacy of sonification for promoting detection.