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Empyreal Radiance: An Application of Sonification in the Field of Astrophysics

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Abstract

Broadly, this paper discusses the application of sonification and its potential for increasing knowledge. The paper is broken up into three sections: the theory of sonification, sonification for artistic purposes, and lastly an extensive look at one process of sonification dealing with solar winds in space. Concerning the theory of sonification, the paper will divulge into the process of sonification and ask questions about the limitations of it as well. The second section discusses how sonification is a way to build the curiosity of not just scientists, but also the general public. The final section addresses my composition *Empyreal Radiance* and contains a detailed account of how I constructed the piece. It is through this section that I relate the ideas of space and sonification together, giving meaning to the title of this paper.

Data for this study was obtained from the DIAL Experimental Data Server, which was jointly developed by Hughes STX and the National Center for Supercomputing Applications under contract to NASA/GSFC (Goddard Space Flight Center). The data is taken from the sun throughout the year 2014 from solar wind data captured from Interplanetary Magnetic Field Parameters (MAG) and Solar Wind Parameters (SWEPAM). Data included is the density of H^+ Ions in the wind and the velocity of wind speed particles. The video included with the composition contains images obtained from NASA's solar dynamics observatory, which is available for public use.

Potential results include an understanding of the field of sonification and how it can help modern sciences. Additionally, the data used demonstrates how sonification can be used when studying the field of astrophysics. Lastly, the composition stands as a completed work of music that can be presented as a blending of both scientific data and musical elements, taking data from solar wind and mixing it with a minimalistic compositional style of music. The composition was

recently premiered at my Composition Senior Recital on March 15th, 2015. Additionally, the video included with the music hopefully enhances the listening experience. Space is often thought of as a silent vacuum, but with *Empyreal Radiance* I hope to show a powerful symphony of sounds using the black expanse above us.

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I. Introduction

A famous movie once held the tagline "In space no one can hear you scream." Although this is true in the fact that the normal human ear cannot hear sounds in the empty vacuum of space, it does not necessarily mean that it is silent. In fact, right now, thousands upon millions of particles make up various motions and sounds in the infinite boundaries of space. How then can we as human beings hear this sound for ourselves? The answer is simple, we can't. We can, however, create representations of this data using technology, in the constantly growing field of sonification. Using sonification, sound artists can create complex sound maps of the great lists of data presented to them. This data comes from various sources, showing how viable sound mapping can be for a variety of disciplines. Early examples of sonification at work include the heartbeat sensor and the Geiger counter. Sonification also presents many opportunities for the way space is viewed by the general public, and by scientists. My research on the study of sonification in space specifically focuses on the application of solar winds and the sound maps I created using the data. In addition, like many other sound artists I went the next step and brought these sound maps into a complex sonification-based composition. The piece, titled *Empyreal Radiance*, shows how sonification can be used to better understand the sun and bringing interest to the general public.

II. Theory of Sonification

To better understand how to use sonification, we should first explain what sonification is and how it works. *The Sonification Handbook* describes it as the transformation of data into a representation that can be heard at the acoustic level for purposes of communication or interpretation. Theories concerning sonification often offer empirically-substantiated, explanatory statements about their relationship with the variables of the data. Also referred to as a subset of auditory display, it is used by a variety of diverse fields such as audio engineering, computer science, mathematics, music, telecommunication and more. There is not yet a set of sonification principles that are easily defined (*The Sonification Handbook* 2011, 9-10). However, starting in the late 1990's work was being done to facilitate a theoretical groundwork for sonification. Kramer et. al. identified four issues that should be addressed in a theoretical description of sonification which include:

1. the presence of a psychologically-based or application-supported taxonomic description of sonification techniques;
2. descriptions of the types of data or tasks that lend themselves to effective sonification;
3. how to treat the mapping of data using acoustic signals; and
4. a discussion of the factors that currently limit the use of sonification (Kramer et al. 1999, 1-27).

Each of these issues has since been addressed in a variety of ways by professionals.

II.1 Taxonomy of Sonification Techniques

Starting with a taxonomic description of sonification, it can be seen as being organized in a variety of ways. They are organized like so:

1. Alarm and Warning Systems
2. Status, Monitoring, and Encoding Messages
3. Data Exploration
4. Art, Entertainment, Sports, and Exercise

Bill Buxton offers us the first two ways in which we can describe the function of auditory display from Chapter 1 in his book *Human-Computer Interaction* (Buxton 1989, 1-9). Data exploration is described by Bruce Walker and Gregory Kramer in their essay "Mappings and

Metaphors in Auditory Display: An Experimental Assessment" (Walker & Kramer 2005, 407-412). Finally, *The Sonification Handbook* states the last, often missed, function of sonification (*The Sonification Handbook* 2011, 12). Each of these functions represents important and unique aspects of sonification that contribute to the field of auditory display as a whole.

Concerning alarms and warning signals, Buxton describes sonification's function as alerts and notifications that are simple and particularly overt. It uses little information concerning these and is meant to represent sonification at its simplest (Buxton 1989, 5-6). However, more complex and modern techniques have been attempted such as categorical warning sounds in healthcare and avionics data being used to modify a given warning sound (Sanderson, Liu, & Jenkins 2009, 788-795/Edworthy et al. 2004, 203-218). Sonification also helps in the function of status and encoding messages. With this sonification takes the information and represents it in sound. This can greatly help with instances of which "the listener's ability to detect small changes in auditory events or the user's need to have their eyes free for other tasks" (Kramer et al. 1999, 3). These auditory displays have been used in a variety of ways with the most common application being the heartbeat sensor we often hear in a hospital.

Data exploration functions act as the third class of auditory display. This is generally what the term "sonification" is used to describe. Unlike status and encoding messages, data exploration uses sound to offer a more holistic portrait of the data presented. This can be used to create vast soundscapes, which blend status indicators and data exploration, or to create auditory graphs (Mauney & Walker 2004, 1-5/Brown & Brewster 2003, 152-156). Sonification also offers a variety of functions for entertainment, sports, and leisure as well, from audio interfaces for simple games such as tic-tac-toe, to audio displays that have been used to facilitate the participation of the visually impaired in team sports (*The Sonification Handbook* 2011, 14-15).

However, it is with art that sonification presents another great use in the form of musical composition. My work *Empyreal Radiance* is one such example of sonification being used to create a musical composition.

II.2 Data Properties and Task Dependency

Beyond taxonomic description of sonification, another issue that needs to be addressed concerning sonification is a description of the types of data or tasks that lend themselves to effective sonification. Concerning data types we can look at information broadly; information can be classified as either quantitative (numerical) or qualitative (verbal). Data is often seen in different ways so it is up to sonification to help distinguish between these differences. Other types of data include nominal data to classify or categorize, and ordinal data, which takes on meaningful order with regards to quantity (*The Sonification Handbook* 2011, 18). Some researchers in the field have given ways to study data using sonification. For example, Barrass states that to order nominal/category data you could use timbre to represent the differences (different types of sounds for different categories) to allow for quicker and easier identification (Barrass 2005, 389-492). However, there is more to sonification than simply figuring out which data you are working with.

There are also many different tasks that lend themselves to effective sonification. Task refers to the functions that are performed by the human listener as they observe the data. This step is a crucial step when considering whether the sonification is a success or a failure, and a listener's knowledge of the task will inform and constrain the design of the given sonification. It should be noted then that there are many different types of tasks, many of which parallel the taxonomies of auditory display described previously.

One of these types of tasks is monitoring. Monitoring requires the listener to attend to the sonification over a course of time to detect events that can occur in the sound and identify the meaning of the event in context to the system's data. Slightly different from this is being aware of a process or situation, where instead of always being attentive to the sonification you simply observe the occurrence of the process. The task of data exploration acts in much the same way as when it is used as an auditory display, including subtasks such as finding holistic accounts of the entire data and finding auditory representations. Point estimation is an analytic listening task that involves extracting information regarding a single piece of information within a data set. Similarly, point comparison is simply comparing more than one datum; in essence this is performing point estimation twice (or more) and then using basic arithmetic to compare the data points. Trend identification is the task of finding a pattern overall, usually an increase or decrease in the data. The final two are the most common: exploratory inspection and dual task performance. Exploratory inspection is the task that involves no priori questions in mind and is simply listening to the data to see what it has to reveal. Dual task performance is when the human listener is performing additional tasks and can accompany the other tasks at hand (not unlike a doctor in a hospital) (*The Sonification Handbook* 2011, 19-21).

II.3 Representation and Mapping

However, once the data source and task are determined, building the sonification involves mapping the data onto representational sound values. There are many different ways to map the data and one method is to take a semantic/iconic approach. As Kramer explains with W.W. Gaver, sound bears some ecological resemblance to the action or process, meaning using icons to note factors in the data help to identify certain actions that occur (Gaver & Kramer 1994, 417-446). An example of this occurring happens no farther than your computer screen. When you try to exit out of a program and it makes a sound, that is an example of semantic/iconic mapping.

Another form of mapping is known as data-to-display mapping. This form of mapping involves deciding which sound attributes are good (or poor) for representing the particular dimension of data. For example, Walker states that temperature is better demonstrated by pitch rather than tempo, as tempo does not allow for change to be heard as easily (Walker 2002, 211-221). However, some sound dimensions (such as loudness) are just not effective in auditory display for practical reasoning (Neuhoff & Wayand 2002, 351-356). Once the sound dimension has been decided, sonification success also requires an appropriate polarity for the data-to-display mappings. Polarity helps to determine how much sound is affected during any given time. Using the temperature example again, as it increases, so does the pitch, when it decreases, the pitch follows. In fact, polarity is not at all unlike that of a slope when graphing in mathematics as it determines both the direction it is moving and how much of the direction at once it is moving. Walker provides a list of some preferred polarities for frequency and tempo under different data sets he discovered through experimentation seen below (Walker 2002, 219).

	Data dimension				
Display dimension	Temperature	Pressure	Velocity	Size	Dollars
Frequency					
Positive Polarity	Good (73%)	Uncertain (50%)	Good (88%)	Poor (35%)	Poor (38%)
Negative Polarity	Poor (13%)	Poor (25%)	Poor (12%)	Good (60%)	Poor (31%)
Tempo					
Positive Polarity	Good (55%)	Uncertain (50%)	Good (92%)	Poor (0%)	Uncertain (50%)
Negative Polarity	Poor (30%)	Poor (25%)	Poor (0%)	Good (100%)	Poor (25%)

Once the mapping has been finished, it is then important to determine how much change concerning the scaling of the data needs to be undertaken. This process can best be described as finding the proper minimum and maximum for the data as a whole, in essences the range of the data. Scaling determines the amount of change that occurs in the data and is the most critical aspect if the sonification is to be successful. In order to make it successful, the user must match the data-to-display scaling function to the listener's internal conceptual scaling function between pitch and temperature. In addition, scaling is the key difference between sonification and a warning or trend monitoring sounds (*The Sonification Handbook* 2011, 25). For example, to represent average daily temperature data from 0-30˚ Celsius, you could use the entire hearing range in frequency (20 Hz to 20,000 Hz) or, instead, shrink it to fill between 1000 Hz to 5000 Hz. Concerning computer music, MIDI (short for Musical Instrument Digital Interface) pitches are often employed instead, often using a range of 33-105 to represent notes A1-A7, or 55 Hz to 3520 Hz (Brown et al. 2003, 284-287). Additionally, pitch bends can be employed to "round" the data value to fit the scale. As can be seen, mapping of the data represents possibly the most complex aspect of sonification, stressing the importance of getting the variables of sound dimension, polarity and scaling right.

II.4 Limiting Factors for Sonification

Many specialists in sonification constantly ponder the factors that currently limit sonification. One such factor is aesthetics and musicality. This concern was first brought up by Edworthy in his article "Does sound help us to work better with machines?..." where he points out the independence of the display performance and aesthetics. Although sound may enhance the listener's aesthetic experience, display performance may not necessarily be impacted by the presence or absence of sound (Edworthy 1998, 401-409). For example, imagine a random stream of data being analyzed by a scientist. Although it may sound interesting to the listener, Edworthy is stating in the article that it may not actually impact whether the sound is helpful to the scientist. Also the musicality of the process has been argued by Brown in his article "Drawing by ear: Interpreting sonified line graphs" where he contemplates whether the use of MIDI instrument banks afford for better sonification principles over the use of things such as pure sine wave tones. Although MIDI notes are more pleasing to the ear for most, they may also hamper the possible message the sonification is trying to address (Brown & Brewster 2003, 152-156).

Another factor that limits sonification is the individual differences of the experience of the listeners. Due to the relative modernity of the field, little is known about the impact of individual differences on auditory display outcomes. To this extent there are several differences that an individual should know concerning sonification. First, by understanding ranges concerning variables, a designer can make a display that accommodates most listeners/users in a given context for that data (Iwarsson & Stahl, 2003, 57-66). In addition, this knowledge of the differences affects the overall success of the sonification. Differences in training among the listeners can often affect performances in a negative way (The Sonification Handbook, 2011, pg. 27). However there are many treatments concerning individual differences in perceptual, cogitative, and musical abilities that can help make the sonification a success.

Concerning the perceptual capabilities of the listener, there are many ways to address this treatment. Detection is the first consideration when addressing perceptual capabilities of the listener. Watson and Kidd state in their article "Factors in the design of effective auditory displays" that the environment in which the listener is in is one of the main factors that affects detection. This includes where the information is being listened to and also how the information is being listened to (headphones, speakers, etc.). Creating an ecologically valid testing condition (one often seen in the real world) and not a controlled environment, offers the best solution for fixing this detection problem (Watson & Kidd 1994, 293-303).

However, how the listener identifies sound also has an impact on the perception of sound. Once again, the use of a controlled environment can skew the data in some instances. However many sonification researchers take to psychoacoustics to fix this. One example is Bregman's theory of auditory scene analysis, which involves using the explanatory data with respect to already pre-conceived sounds known in society (Barrass & Best 2008, 1-6). It is through this, then, that the perceptual capabilities of the listener can best be addressed.

Also, cognitive abilities in sonification still remain relatively unexplored as of today. In addition, few studies have examined whether the relationship between cognitive abilities and auditory perception even have an effect of sonification. One studies found though that spatial reasoning ability does produce some variance in performance with auditory graphs (Walker & Mauney 2004, 1-5). However, this is still a relatively unknown field. Additionally, there are still many questions asked by sonification researchers concerning this area. One researcher argued, "Sonification monitoring tasks employ template matching processes, then what are the properties of the stored template and how are they formed?" The same researcher asked if people that listen to auditory graphs attempt to translate them into a more visual representation of the data (Kramer 1994, 1-78). Still even with questions, most researchers tend to shy away from the theoretical sciences in favor of more applied research in sonification, meaning these questions may remain unanswered for quite some time.

Musical ability is also said to affect tasks involving auditory displays. In fact musical experience and ability has determined at what level a listener would be able to perform concerning how they registered the data (*The Sonification Handbook* 2011, 29). However, many researchers have studied that these levels are very minor and even the worst musician should still be able to register the majority of the data. This same study suggested that those using sonification, should at the very least, take minor music lessons to better comprehend the data (Edwards et al. 2000, 1-5). However, Watson and Kidd described this impasse best by suggesting that the auditory perceptual abilities of the worst musicians are likely better than the abilities of the worst non-musicians, but the best non-musicians likely operate at the same level as those of the best musicians (Watson and Kidd 1994, 293-303).

Many researchers agree that training of sonification offers the best path forward in order for it to be used for more and more applications. Although now seen as a novel approach to information representation, this novelty stands as a barrier to the success of the display unless the user is trained on how this sound is presented (*The Sonification Handbook* 2011, 30). One group of researchers note that all children learn how to read visual graphs at a very early age and suggest that auditory graphs should be made simpler to allow for more to comprehend those (Zacks et al. 2002, 187-206). However, many agree that before we introduce sonification for training among the general public, the researchers listening and creating the sonification should first go through the process. Walker and Nees found in their research that as short as a 20 minute training period can reduce error by 50% on the point estimation sonification process (Walker and Nees 2005, 276-279). Therefore, the theory of sonification, although relatively new, is also very exciting. There is much work to be done in the field, but by accepting the limitations, auditory data can hopefully be better understood and help with processing the data we deal with in research.

III. Sonification for Artistic Purposes

What has been discussed has largely dealt only with the theoretical aspects of sonification, but a question remains: although it can be used by scientists for data study, what is another way that sonification can be used for general interests? In the previous section it was discussed that sonification and auditory graphs are often seen as too complex for the general public to usually understand, but does that always have to be the case? In his article titled “Sonification, Science and Popular Music: In search of the ‘wow’”, Mark Ballora offers a way in which sonification can be viewed differently. He starts the article with this: “Sonification is currently an under-utilized element of the ‘wow!’ factor of science.” The ‘wow’ factor he is referring to is the idea of using sonification as an entertaining art form for listening, similar to the artist interpretations we see on popular science programs like PBS’s *NOVA*. He argues that the ‘wow’ factor has just as important a contribution as that of any other aspect of sonification, due to its ability to drive the curiosity of an engaged audience. These audience members then become more interested in the science due in part to these factors, and some go on to become future scientists or potential funding sources (Ballora 2014, 30).

Ballora adds to his argument by stating that sonification is simply the next evolution of how we comprehend science. He states, “As information sources multiply, it seems implausible to expect that the eyes alone can make sense of everything. After all, the eyes and ears play complementary roles in our awareness of everyday life.” From there he goes on to discuss how visualizations make a vital part of our everyday life and it seems frivolous to disregard hearing when it comes to the complex information we make out every day (Ballora 2014, 30). In addition, A.S. Bregman says in his article “Auditory Scene Analysis: The Perceptual Organization of Sound” that the auditory system can more easily follow multiple sources of information than the visual system (Bregman 1990, 1-8). From there Ballora then goes on to talk about recent examples of sonification that contain what he believes to be the ‘wow’ factor.

One example he includes is a project by Mickey Hart, former drummer of The Grateful Dead. *Rhythms of the Universe*, started in 2010 with Nobel Laureate George Smoot, is a “multi-sensory exploration of the universe” which takes data from various galaxies (Smithsonian 2013). The piece makes use of unique pitches and rhythms to demonstrate the vast expanses of space, and serves to show how sonification can used to bring the ‘wow’ factor to the general public

(Hart & Smoot 2013). Mickey is just one of many artists that are turning to science for inspiration in their music, Ballora says. “Whether the objective in creating a sonification is to better analyze a problem, to make music or to explore auditory perception, success in one area will be likely to spread to the others” (Ballora, 2014, pg. 31). If Ballora and other sound scientists are to be believed, sonification represents the most important landmark in data analysis since the creation of graphs themselves. Thus, the ‘wow’ factor, the intrinsic urge to explore, is very important for both the field of sonification and the future of data analysis.

IV. Empyreal Radiance

In the previous sections, I have discussed how sonification can affect both scientific inquiry and the ways with which it can generate curiosity. This, however, represents only some of the many aspects of sonification. To create the composition *Empyreal Radiance* (the name meaning “celestial light”), I had to follow many of the steps I described earlier concerning the theory of sonification. The first step of the process concerning making the piece was deciding which data I was going to use. I decided to use solar wind data, as that was the data I was most comfortable with. The data used for the piece was taken from the sun throughout the year 2014 from solar wind data captured from Interplanetary Magnetic Field Parameters (MAG) and Solar Wind Parameters (SWEPAM), particularly the density of H^+ Ions in the wind and the velocity of wind speed particles. This was obtained through the DIAL Experimental Data Server, which was jointly developed by Hughes STX and the Nation Center for Supercomputing Applications under contract to NASA/GSFC.

In order to create a successful sonification though, I needed to decide how to properly map the data. Using a program called Max (formerly Max/MSP), I took the data obtained from the solar winds and mapped them using a series of command interfaces called “patches” in the program. There were two patches I created in the program in order to supplement the data that I was presented, and the first of the two can be seen in the figure below.

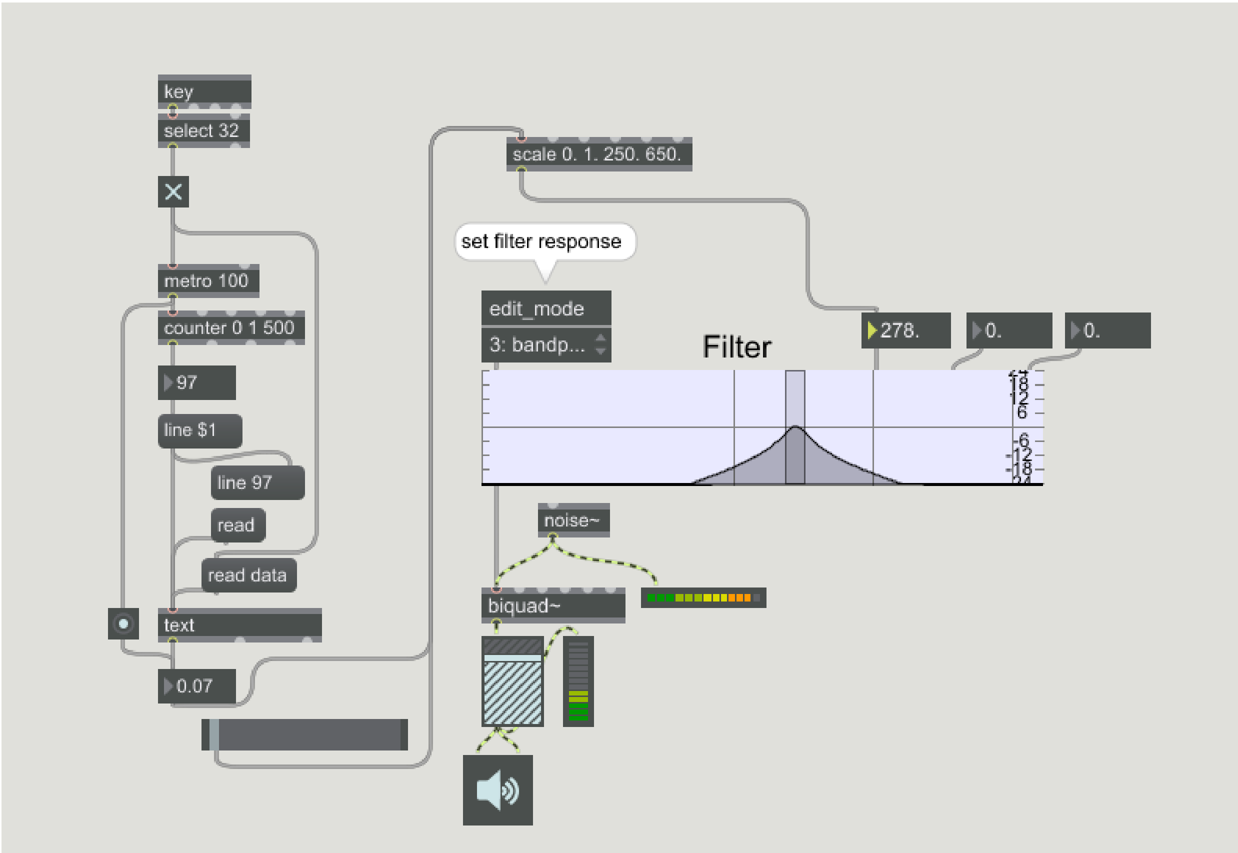

Fig. 1: Sonification Patch used for Velocity of Solar Winds

This figure above shows the patch used for presenting solar wind velocity. The top part of the patch has the activation setup for the patch with the "key" module connecting to "select 32"; the patch is started by hitting the spacebar. The spacebar is connected to a "toggle," which is similar in function to a light switch (showing a white x when the patch is on and nothing when off). From there, the toggle is connected to two objects, a "metro 100" object to control the rate at which the data changes (in this instance it is 100 ms) and a message object saying "read data" which pulls the txt file called data.txt from the same folder as the patch and loads it. The most important part of the patch lies right below the “metro 100” object with the stream of three objects below it.

The “counter 0 1 500” sets your counter for what lines of data you are going through. The number box below serves as a reference to know where in the data you are. Finally the message object “line $1” serves to take the data file and reads it one line at a time. By adjusting the counter, we can set which line of data we want to start at and how far into the data we want to go. Beyond that setup, we have a “text” object which is where the data has been collected, which in turn is connected to another number box that tells you the specific data coming out of the given list. The white dot in the figure is called a “button” object that helps to reinforce the “bang” sent out from the “metro 100” object. From the data part of the patch (left side) we go onto the right side, which does a majority of the sound processing.

To start, the “scale 0 1 250 650” does the scaling of the data, which in this instance maps the data going from 0-1 onto a value between 250-650. This affects the center frequency of the filter graph seen below the scale object. The “filter graph” objects generate and filter out certain variables based on whether they fit into the graph. For this, as the center frequency increases the sound gets slightly louder and higher pitched, with overall amplitude envelope represented by the curve in the graph. The sound that is being affected is white noise (often known as that sound that protrudes from a TV when the channel is wrong), generated by the “noise~” object. From there, both the “filter graph” and the white noise are channeled into a “biquad,” a common type of digital filter. The scaling object below affects the volume before finally being followed by the speaker icon, which is the final sound output.

The goal of this patch is to affect the white noise being produced. With the use of the filter graph, the white noise changes into somewhat of a wind sound. Thus, by putting the velocity data into this patch you can easily hear the sun's wind. How fast the velocities of the ions are affects whether the wind is higher or lower pitched, not at all unlike wind heard on Earth.

The other patch used in the composition deals with density. It contains some aspects that are very similar to the wind patch, but as seen in the figure below, there are also many differences that affect how the data sounds to the ear. This particular patch affects pitch and plays different MIDI notes depending on what data point is being used. This is a very common way of using sonification. However, there is a difference that sets this patch apart from some other patches concerning this kind of sonification and can be seen in the figure below.

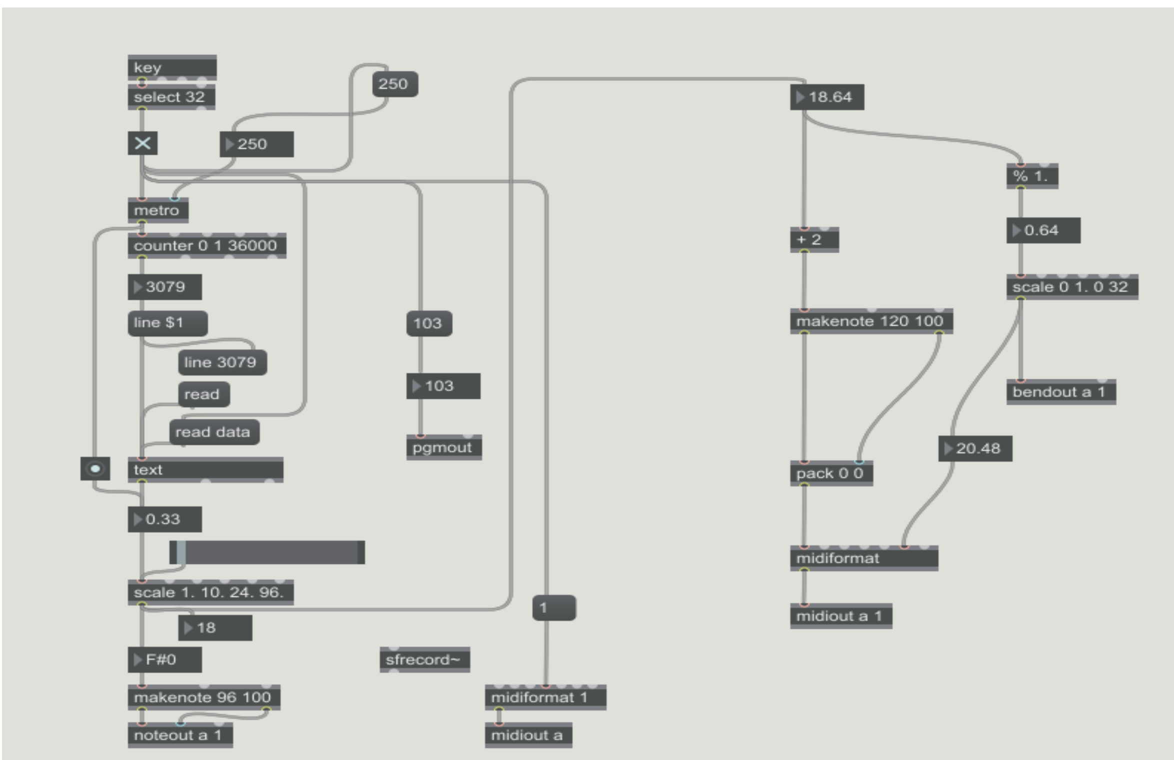

Fig. 2: Sonification Patch used for Density Ions of H^+ Ions

As can be seen in the figure, the part up to the "scale" object should seem pretty familiar to the other patch seen in the previous figure. The differences lay with what's underneath it and to the side of it. Beginning below the "scale 1 10 24 96" you see an object called "makenote 96

100”. This object outputs a MIDI note with certain parameters. The “96” part represents the velocity (how loud the note sounds), while “100” is the notes’ duration (for this one 100 ms). Connected to the “makenote 96 100” object is the “noteout a 1” which acts similar to the speaker icon for the other patch; it plays a note on the synthesizer. Connected to the “toggle” object is a message object saying “103” which is connected to an object called “pgmout”. This object affects what kind of instrument sound you are using for the piece. Assuming a default MIDI bank is loaded, “103” corresponds to MIDI instrument 103, a synth sound FX instrument called “Echoes”.

The part off to the right of the patch, though, is what makes this patch unique from other sonification pitch displays. This part starting with that number icon is connected to the scaling object as well (not unlike the “makenote” object). However, below it lies an object seen as “+2” which increases the variable 2 above before going into another “makenote” object. This produces a note sounding slightly higher than the other note giving a harmonic aspect to the piece. To prevent this from sounding jarring to the listener, a pitch bend is utilized with the “bendout a 1” object affecting the bend of the pitch. However, the data also is also affecting the rate of the bend with modulo % (i.e. takes the decimal point) of the data’s value being the amount of bend that causes the pitches to weave in and out. Therefore, unlike the other patch, which was clearly more for stressing scientific data, this patch makes the data more musical to listen to.

After recording the sound produced by the sonification patches, the process of creating the composition begins. To create an electronic composition there is a variety of ways to go about it. For fixed media (music doesn’t change with performance), the composer typically uses a digital audio workstation (DAW). Popular examples of these include ProTools, GarageBand, and Logic. The DAW that I used for this composition was Cubase, specifically Cubase Elements

7. After obtaining all the sounds I need recorded, I take them and place them into the program. To add interest to the work I manipulated the volume levels, and I timed sounds at different moments for interest. In addition, I later added another layer of minimalistic music, the sheet music, some of which can be seen below.

Fig. 3: Sheet Music for *Empyreal Radiance*

From the sheet music, I plugged the notes into the program through MIDI input function. After that, I applied volume and other extra features to add the finishing touches. One example of a finishing touch I made for this piece that can best be heard with stereo sound speakers is the bass drum, whose sound pans from the right speaker at the beginning of the piece all the way to the left speaker at the end of the piece to represent the rising and setting of the sun. A portion of the completed composition is seen in the figure on the next page:

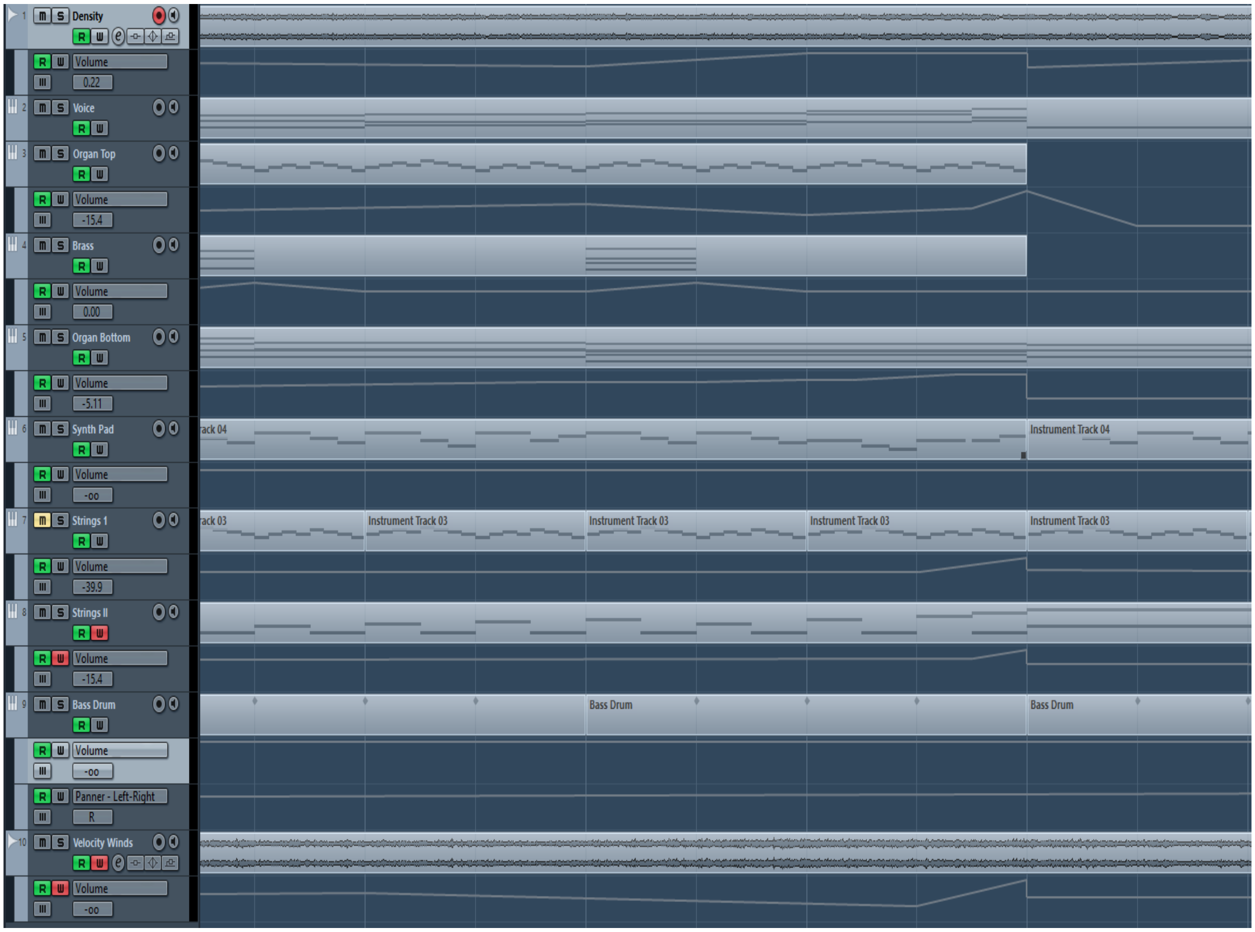

Fig. 4: Cubase Interface for *Empyreal Radiance*

As seen in the figure, there are many layers involved in creating a fixed media piece. The sound files used for the sonification are the density line at the top and the velocity winds line seen at the bottom. The rest are the MIDI instruments which add to the sonified sounds. Below each line, the volume adjuster is visible which allows the user to build and lessen the dynamics for the piece.

The final piece of my composition *Empyreal Radiance* that has not been discussed is the video. Most of the videos were taken from NASA's solar dynamics observatory which is available for public use. Although they are not directly related to the density or velocity data they do serve to add to the ‘wow’ factor of the sonification. The video acts as another way to drive curiosity about space and how sonification and visuals can be used together.

Although *Empyreal Radiance* is still a very basic sonification composition, it works to show the complex process of creation for both the sonification models (in the form of Max patches) and the electronic composition that can come from it.

V. Conclusions

For the longest time science had often only relied on the visual aspects when concerning data, but with sonification we can gain more insight than we ever realized was previously possible. Space is often thought of as a silent vacuum, but with *Empyreal Radiance* I hope to show a powerful symphony of sounds using the black expanse above us. To me, that is what sonification best represents, constructing a symphony of sounds to explain complex data. As seen in this paper, there are many steps to constructing an auditory display for sonification to be used. Additionally, there are many limits to how far we can go with sonification thus far. Beyond the scientific aspect of sonification, some sound artists are trying to find that ‘wow’ factor in order to generate curiosity about the data we are listening to both for the scientists and the general public. Lastly, *Empyreal Radiance* illustrates an example of the complex process in making a sonified model. Beyond that it also goes to show the additional work needed to construct an electronic composition based around it.

Sonification will still play a very important part for me in the future. Going for graduate studies in aerospace engineering at Worcester Polytechnic Institute, I plan on constructing many more auditory displays for use in the field of astrophysics. Eventually I would like to continue implementing sonification for space studies. With sonification models and compositions becoming more prominent, I hope to help bring whatever contributions I can to the field.

Empyreal Radiance is only a small step in this massive journey of understanding space, but as it was once said when we landed on the moon, “This is one small step for a man, one giant leap for mankind.”

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