# Sounds of the Stars: Sonification of Stellar Pulsation Modes
## *An Interactive Outreach Poster*

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## 1 Introduction

'Sounds of the Stars' is an interactive poster designed for outreach events. It uses sonifications of stellar pulsations to help members of the public get a better idea of what happens to a star as it evolves. The sonifications were generated in Matlab from models of a solar-mass star. The interactive aspect is the use of capacitive proximity sensing, achieved using conductive paint and a printed circuit board (PCB) from Bare Conductive [`https://www.bareconductive.com/`]. The poster focuses in three stellar properties: the pitch change as the star expands, the presence of mixed modes as the interior structure changes and the beating introduced by stellar rotation. Materials related to the poster design (including Matlab codes, images and sound files) are available online at `http://www.asterostep.eu/Outreach.html`.

## 2 Generating Sounds

All sounds used on the poster (with the exception of the audio instructions) were generated in Matlab codes. The **musicalstars.m** code was used for all sounds in the radius and mixed mode sections, while the rotation sound was from **rotation_musicalstars.m**. Both codes and the required functions are provided online.

**musicalstars_E.m:** loads the frequency files from the models; sets the sampling rate, conversion factor and sound length and allows selection of modes to superpose and whether to randomise the sinusoid phases. Then calls the **create_starmusic** function which creates an intensity array. This array is converted to sound using the '*sound*' command. To generate the audio file, a tapered cosine window is applied to the intensity array, before the '*audiowrite*' command is used to produce the wav file.

**rotation_musicalstars.m:** uses the same **create_starmusic** function, but in this case superposes three frequencies which vary linearly in with time. The central frequency and splitting can be altered to reflect different stellar properties.

## 3 Design

The poster design has three main components. The text, header and footer were written and edited in PowerPoint; the central HR diagram and frequency plots were generated in Matlab and the stellar cross sections were created in Inkscape. The frequency spectra were generated with **musicalstars_E.m:** and the rotation interference patterns with **rotation_plot.m**. The codes and image files are available online, along with the cross section images and Inkscape projects, and the full poster design.

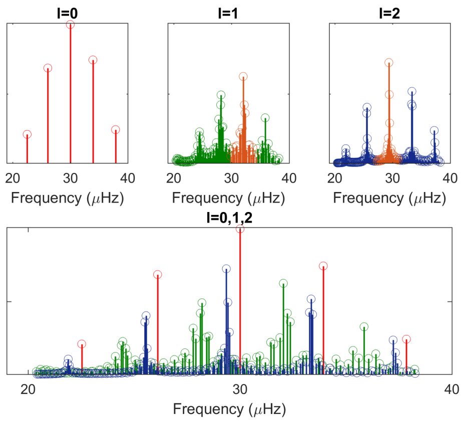


Figure 1: Example frequency spectra (Stellar Model 5)

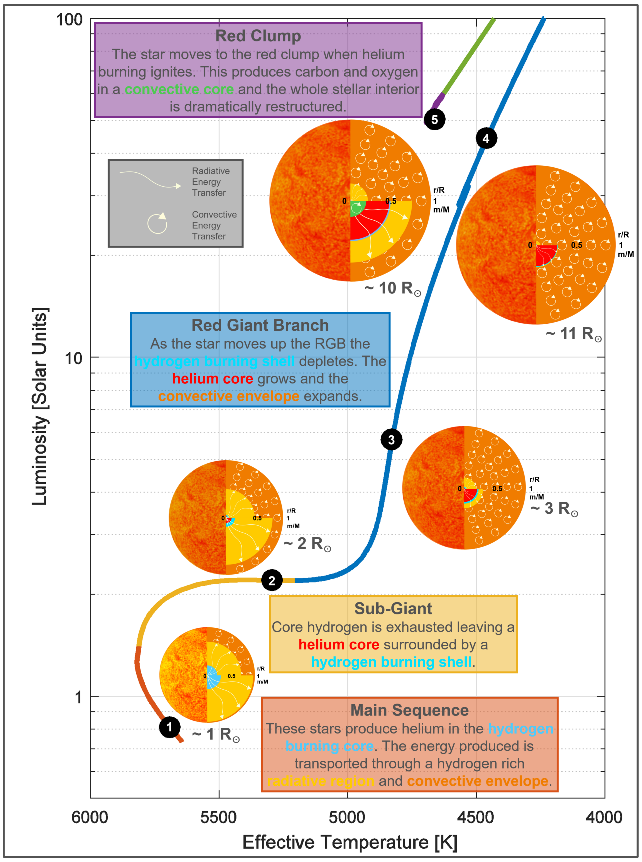


Figure 2: Central plot showing HR diagram and stellar cross sections

The poster setup uses the Bare Conductive conductive paint and 'Touch Board' PCB. The website contains numerous help sheets and tutorials, but the information relevant to this project is collated here. The poster paper is velcroed to the foam board backing, to allow access to the sensor setup if required.

### 3.1 The Touch Board

The touch board is the white PCB attached to the bottom right of the poster. It contains a microcontroller which can be programmed with the Arduino IDE, and dedicated capacitive touch and MP3 decoder ICs. The code used for the poster is available online, with the required libraries, and details of how to program the board are available here: `https://www.bareconductive.com/make/setting-up-arduino-with-your-touch-board/`

**Changing the sound selection:** Simply change the tracks on the top-level of the micro-SD card – no programming is required. The board can support up to 12 tracks, named 'TRACK000' to 'TRACK011', which play when the electrode (or sensor) 0 to 11 is triggered. Sound files must be in MP3 format. I found during this project that – for some reason – MP3s produced directly by Matlab do not work with the board (and, in any case, the 2017a version I used doesn't seem to produce MP3 files at all!). My workaround was to produce wav files from Matlab and then convert them to MP3 using the 'Audacity' audio editing software. To do this, open the wav file in Audacity and then select 'File; Export Audio' and choose MP3 format.

**Changing the Volume:** This requires a small change to the programming of the microcontroller. For this reason I found it simpler to use speakers or headphones with 'on-board' volume control. If this is not possible, the required change is to line 97: "MP3player.setVolume($\boldsymbol{x}$, $\boldsymbol{y}$);". Here, lower values of $\boldsymbol{x}$ and $\boldsymbol{y}$ indicate higher volumes: "(0, 0)" sets both channels to maximum, while "(254, 254)" is silent.

**Changing the proximity sensitivity:** Depending on the situation, it might be useful to make the proximity sensors more or less sensitive. This requires a change to lines 90 and 94: "MPR121.setTouchThreshold($\boldsymbol{a}$);"; "MPR121.setReleaseThreshold($\boldsymbol{b}$);". Higher values of $\boldsymbol{a}$ and $\boldsymbol{b}$ decrease the sensitivity. Note that the release threshold must always be lower than the touch threshold.

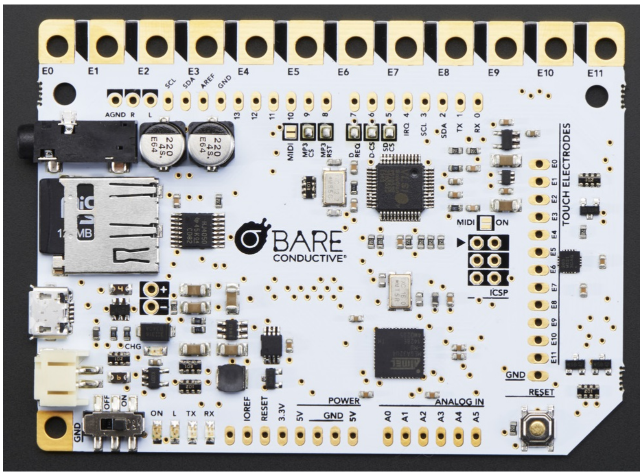

Figure 3: Bare Conductive Touch Board

### 3.2 'Proto Shield'

the black Proto Shield PCB on top of the Touch Board is only used to provide the wired connections without needing to solder them directly to the Though Board PCB. The Touch Board and Proto Shield can be separated by gently pulling apart (the headers will separate – be careful not to bend the pins). The wires can also be removed by unscrewing each terminal. The two PCBs are velcroed to the poster paper so if access to the board behind is required the PCBs can be separated from the paper and the paper removed from the board. NB: Please be careful if doing this! The wires are connected permanently to the board so try not to pull them when moving the PCBs.

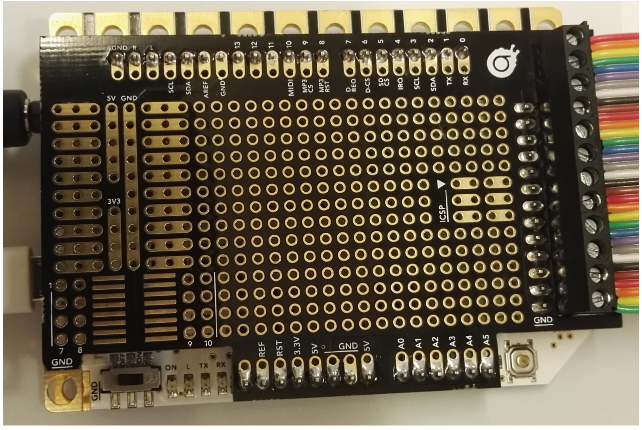

Figure 4: Bare Conductive Proto Shield mounted on the Touch Board

### 3.3 Conductive Paint

The proximity sensors are discs of 11cm diameter, painted with the conductive paint. They are stuck to the board behind the poster paper and connected to the Touch Board with copper tape. The paint was also used to ‘cold solder’ the wires from the PCB to the copper tape. This is all now hidden under the black insulating tape. The sensors are ordered 0 to 10 anticlockwise from the Touch Board (Figure 5). The track listing is shown in Table 1

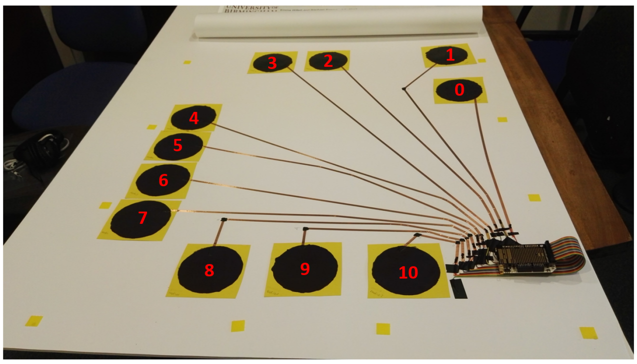


Figure 5: Sensor Layout

Table 1: Track list, stellar model number in brackets

| Track Number | Sound |
|---|---|
| 0 | Rotation (4) |
| 1 | Instructions |
| 2 | l=2 (4) |
| 3 | l=2 (5) |
| 4 | l=1 (5) |
| 5 | l=1 (4) |
| 6 | l=1 (3) |
| 7 | l=1 (1) |
| 8 | l=1,2,3 (1) |
| 9 | l=1,2,3 (2) |
| 10 | l=1,2,3 (3) |
| 11 | Unused |

## 4 Outreach

At the time of writing, the poster has been displayed at the TASC3 KASC10 Workshop (`http://www.tasc3kasc10.com/`) and the public lecture connected to it. This section collects the thoughts I had over the week of the conference – advice for helping people get the most out of the poster and the questions I was asked most.

### 4.1 General Advice

**Instructions:** In a noisy room, it’s probably best simply to tell people how to use the poster as the spoken instructions may be too quiet. the transcript is: *“Wherever you see the black handprint, there’s a sound you can play. To listen, put your hand close to the centre of the box containing the handprint. The number in the hand corresponds to the number on the HR diagram. You can adjust the volume using the dial on the left side of the headphones.”*. With people who did listen to these instructions there were a few things that weren’t always noticed. First, that the sound locations are indicated by the handprints but that the sensors are in the centre of the boxes. In many cases people tried to play sounds by touching the stellar cross sections or by pushing on the small handprints as if they were buttons – often I found it easiest to show people how to use the poster instead. It is possible to play some of the sounds by putting your hand near the centre of the poster, but this is due to the presence of the copper tape and not an intentional sensor. This can lead to some confusion!

Second, it often helped to re-iterate that the numbers in the handprints do not correspond to some order in which to play the sounds – they match up to the stellar models. In general I think it would be best to use this poster with someone around to explain how it works, there's quite a lot going on and without taking the time to read the details it can be a bit confusing.

**Headphones:** There are a few things related to the headphones bought for use with this poster that it's probably worth being aware of. First, they can pick up quite a lot of radio interference. There's always a background of static, but sometimes they tune to other radio signals instead of that from the dock. This is easily resolved by pressing the 'Autotune' button on the left hand side of the headphones. I found it usually happened when the headphones were switched on after charging for a while. If they haven't been used for a while it may be good to check everything's working before letting someone else use them. Second, while I haven't had any problems with their battery life, keep in mind that the headphones will only charge if switched off and sat correctly in the dock – check for the green light on the front.

**Resetting:** If one of the sensors is triggered wen the Touch Board is switched on (or reset) then that state is taken as the 'base-level' setup and that sensor can no longer be triggered to play a sound. The reset button on the bottom right of the touch board will correct this. The orange LED will flash as the system resets, once it has turned off the poster is ready to use again.

**LEDs:** It's possible to check that everything is working properly while someone else is using the poster. The orange LED (next to the green power light) is on while a sensor is triggered. If it doesn't light, or doesn't turn off, reset the touch board. There's no need to keep your hand over the sensor while the sound is playing and if you don't remove your hand far enough the next sound might not play.

### 4.2 Common Questions

**How does it work?/ What does the circuit do?** To answer these questions I found it helped to have the tub of electric paint, a spare sensor and pictures of the board under the poster on-hand to explain. Using the example of a theremin helped to describe how the sensors worked and the circuit is basically set up like an mp3 player.

**Why are the pitches different in some sounds and not others?** All of the stellar 'sounds' must be sped-up by a factor of about a million to bring the frequencies into the audible range. The set of three rotation sounds have a constant conversion factor – hence the pitch changes between the three. This is also why only the first three stellar models are included: to make the main sequence star (relatively) comfortable to listen to, the conversion factor is such that the upper red giant and the red clump star are too low to be clearly audible. The sounds connected to the mixed modes explanation are all matched to have the same pitch. This is because the differences between them are quite subtle and very difficult to hear if the ear is already distracted by the pitch changes. The sounds are also only made up of the central, orange peak of the frequency spectrum. The more frequencies you listen to, the more similar the sounds become so the central regions were isolated to make the differences more pronounced.