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SOUND-DRIVEN DESIGN IN ASTRONOMY: THE LONG-TERM IMPACT OF DESIGN AND EVALUATION ACTIVITIES ON THE DEVELOPMENT OF ASTRONOMICAL DATA SONIFICATION TOOLS

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ABSTRACT

Interdisciplinary, collaborative workshops are one of the core activities in design disciplines. In design literature many descriptions of methods and analyses of results can be found. But can these activities have a long-term, transformational impact in the way practitioners develop their designs? The Audible Universe (AU) project aimed at developing sonification processes in the astronomy field. In this frame, the second AU2 workshop brought together, for 5 days in 2022, about 50 experts (astronomers interested in sonification, software developers, sound designers, experts in sound perception and educators) to exchange knowledge on how to approach the sonification of astronomical data. One core aspect of the workshop were ideation and evaluation sessions to introduce and provide practical methods for the design of sonifications. This paper presents a systematic analysis of the materials produced during these sessions based on shared environments and protocols used by participants, and through two follow-up interviews with software developers reports on the long-term impact that these sessions have had on the development of two specific tools for astronomical sonification.

Keywords: sonification, astronomy, design, evaluation, workshop

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1. INTRODUCTION

Data visualization is used in most scientific fields to portray information to both expert and non-expert users. Since childhood, people learn how to interpret basic building blocks such as shapes, colors, coordinate systems. But visualizations are not universally accessible, and they require attention in a specific direction. Recently, the benefits to develop auditory and multi-modal displays in STEM (science, technology, engineering and mathematics) fields such as astronomy has become increasingly apparent [1], as these displays have the potential to improve accessibility for BVI (Blind/Visually Impaired) scientists and students, and portray multidimensional datasets for outreach, research, or education in an engaging way. Sound has many advantages as a display of information: it is omnidirectional, it can be used as a method for touchless control, and it can portray complex information in a short amount of time [2], but knowledge on how to design and evaluate auditory displays is not widely spread. In this paper, the outcomes of design and evaluation sessions developed within the Audible Universe project will be analyzed, as well as their impact on the development of two software tools: STRAUSS and HERAKOI/EDUKOI.

2. BACKGROUND

In a systematic review of the International Conference on Auditory Displays proceedings, García-Benito [3] has shown that, in the last 10 years, sonification studies in astronomy have rapidly increased. Zanella et al. [1] analyzed nearly 100 sound-based astronomy projects and concluded that research efforts should concentrate on developing standardized sonification solutions; evaluating their efficacy; and developing cross-disciplinary networks. Sound, as a design material, presents two main challenges: the lack of a shared vocabulary [4] and the lack of established sonification standards [2]. For this reason, to develop effective designs for a particular dataset and context, a close communication loop between sonification designers and target domain experts is necessary. Such dialogue requires a degree of knowledge of each other's disciplines, as well as time and availability. A useful next step in sonification design is then exploring methods to bring diverse stakeholders together.

Participatory Design [5], i.e. the use of workshops to explore a design space and context, harness creativity, and ideate through scenario building, lo-fi prototyping and role playing [6], entered the field of auditory displays about 20 years ago. Franinovic et al. [7] utilized methods from industrial design, ethnographic inquiry and theatre, to develop sonic interaction prototypes in a participatory manner. More recently, participatory approaches have been used in areas such as sonic interaction design and energy efficiency, embodied sound design, and critical alarms [8–12]. The Sonenvir 3-day workshop is a prime example of participatory event in which sonification and domain experts, tool developers and scientists, were brought together to develop sonification ideas for applications in various scientific fields [13]. In interdisciplinary teams, participants ideated novel sonifications for given datasets and then presented them to all. Participants were positive about results and felt that the workshop increased their understanding of the sonification discipline. Nonetheless, they suggested that longer pre-workshop preparation and workshop duration would be helpful. Goudarzi et al. [14] developed a workshop in which sound experts and scientists worked on predefined and exploratory tasks to sonify climate data. Time pressure was again perceived as a drawback, while hands-on sessions were positively received. The workshop organisers concluded that particular attention should be given to tackling the domain scientists' initial skepticism towards sonification.

While participatory methods are now well-established in design and even in sound disciplines, research on how workshop activities impact on the development of new technology is very limited. Elsden et al. [15] highlight the potential pitfalls of workshops, describing them as 'deeply ambiguous activities' due to the often unclear expectations regarding outcomes and participant commitment before, during, and after the event. The authors mention that in the absence of follow-up (often the case in workshops), the ideas generated through collaborative and open-minded engagement may fail to progress toward practical implementation. For this, carefully considering workshop structure is important as it affects the clarity of aims and expected outcomes, as well as the relation between organisers and participants [16]. This paper describes the structure and offers a systematic analysis of the materials produced during a sonification workshop for astronomy. Moreover, through follow-up interviews, it examines the workshop's long-term impact on the development of two astronomical sonification tools.

In 2021, the Audible Universe (AU) project emerged from discussions between astronomers interested in sonification, and experts in sound perception and design, together with psychologists, and educators [17]. The main goals were to increase BVI accessibility to astronomy, develop engaging and inclusive educational resources, and develop innovative methods for scientific analysis and investigation of large datasets. Two workshops took place during the project [1, 18, 19]. The goals were to consolidate the state-of-the-art, foster multidisciplinary discussions on astronomical data sonification, work towards a scientifically-driven approach to sonification design, and develop suitable methods to evaluate sonification tools for astronomy. Fifty experts (astronomers, sound designers, sound perception experts, and educators) worked together during the latter 5-day workshop (AU2) that included introductory lectures and splinter sessions on sonification, design, and evaluation stages. Six digital tools (detailed in [17]) were selected to be explored in these sessions. The workshop had 3 focuses: astronomy as a target domain; evaluation of sonification (as a follow-up stage from design ideation); and the use of design and evaluation tools (e.g Data Sonification Canvas [1] and a JsPsych platform [2]). A detailed description of the workshop framework can be found in [17].

3. DESIGN AND EVALUATION SESSIONS

The design and evaluation sessions took place over two and a half days. Participants were divided in 6 interdisciplinary groups (3 in-person and 3 hybrid). The overarching aim was that, during these sessions, participants would become familiar with two key stages of the design process referred to as Generation (or Ideation) and Evalu-

[1] https://sonification.design/assets/resource/Data_sonification_canvas.pdf

[2] www.jspsych.org/

ation stages by Cross [20]. Each group included tool developers, astronomers (sighted and BVI) and sound experts. In each group, two people with expertise in design were selected by the organizers as moderators with the responsibility to facilitate the work efficiently. Both design and evaluation activities consisted of two 1,5-hour collaborative sessions. At the end of each activity results were presented to all.

In the design sessions, participants were asked to ideate and possibly sketch new features for one of the six astronomy sonification tools. They were encouraged to utilize a divergent and explorative mindset. Moreover, participants were instructed that ideation should target one or two design characteristics chosen among those identified in the first AU workshop: accessibility, standardization, multimodality, analogy, interactivity, training, efficiency and usability (see [17] for details). The Data Sonification Canvas by Ciuccarelli and Lenzi (see above) was provided as a tool for ideation, offering a systematic way to reflect on different aspects of a sonification design: use case, sonification approach, mapping choices, and listening experience. In the Canvas, each section is subdivided in sub-sections accompanied by guiding questions. Expected outcomes of the design stages were: one Canvas-based description of the existing tool, one Canvas-based description of the ideated tool (see Fig.1 for STRAUSS), one "Record of work" document with a brief description of the group thought process and, optionally, auditory or visual sketches of the updated tool.

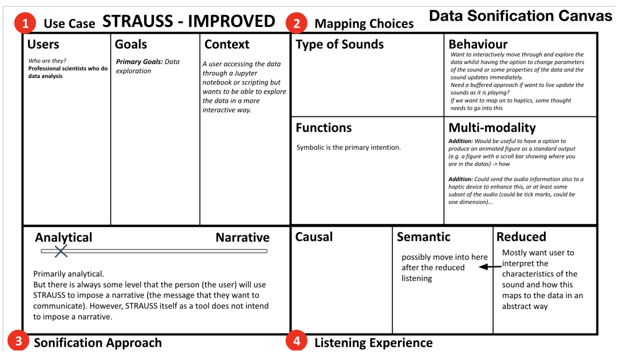

Figure 1. STRAUSS Canvas filled in a design stage.

In the evaluation sessions, participants were asked to consider how they would evaluate the features ideated during the design sessions. Several resources were provided: a video tutorial on the "Perceptual evaluation of sound-producing objects applied to data sonification", an article with a list of relevant evaluation methods [19]; and an online toolbox, developed in jsPsych (see above), providing access to experimental paradigms templates. Expected outcomes were: one or two experimental designs; one "Record of work" document describing the group's thought process and, optionally, the implementation of one experiment in JsPsych or other platform of choice.

4. ANALYSIS OF THE SESSIONS OUTCOMES

Each group addressed a different software, and each group included a developer of that software. Section 4.1 reports on the outcomes of the Design sessions, while Section 4.2 reports on the outcomes of the Evaluation sessions. For sake of conciseness, only the tools (HERAKOI/EDUKOI and STRAUSS), which are further investigated in section 6, are presented hereafter.

4.1 Design sessions

Main takeaways from design stages can be found in [17], while detailed descriptions of results for HERAKOI/EDUKOI and STRAUSS are reported below.

1. HERAKOI/EDUKOI. Multi-modal interaction and multi-sensory representation were the design characteristics addressed by this group. The original purpose of HERAKOI, which allows to explore images with hand movement, was outreach and, after discussion, the group decided to ideate new features to improve accessibility for a BVI audience. Additionally, the group decided to widen the purpose of the tool to *"STEM education and children above the age of 5"*. The group described the purpose of the updated tool as *"making astronomy a multisensory experience and spark interest from a young age"*. A variation of the tool was ideated and called **EDUKOI**. The original sound-to-data mapping was considered to be quite arbitrary. Therefore in EDUKOI, the user should be able to have more control and choose the sound-to-data mapping. A new suggested mapping was: bright colors should be mapped to sharp sounds (high frequencies); non-bright colors should be mapped to dull sounds (low frequencies). Additionally, a tactile frame could be provided to facilitate wayfinding and image formation for BVI users. Overall, EDUKOI should facilitate the telling of a story about the image under consideration, i.e. utilize a narrative approach to sonification. In the "Record of work", this group rather uniquely considered the economic affordability of EDUKOI. As general feedback, all participants stated that they learnt a lot from discussing design approaches and the need for a common terminology in sound design and sonification.

2. STRAUSS. This group addressed interactivity and multimodality. The purpose of the original tool was data analysis, and the original target audience was STEM University students. The new tool would target a wider audience inclusive of professional scientists. Interactivity would be implemented to aid accessibility. In the original software application, the user is in charge of deciding the sound-to-data mappings. Sound spatialization is also possible. The updated tool should provide *"interactive, real-time ways of changing mappings and navigate the data"*. The group imagined to add haptics to provide user interface elements like graphs tick marks. The group thought that data-to-sound mappings could remain symbolic (i.e. based on reduced listening-being able to follow various aspects of sound, such as pitch, evolving in time) because the purpose of the tool would remain data analysis. The underlying reasoning seemed to be that if the mapping is effective in allowing data analysis, it does not need to be explicitly connected to the data through an analogy or association. The group stated that the tool *"should not impose a narrative"* (see Fig.1). The group thought that the primary listening mode would be reduced, but with training this could become semantic (i.e. the data-to-sound mapping is learnt through experience and the underlying connection between sound and data could become more immediate to the experienced user). The group considered adding zooming and scrolling features. Redundancy, i.e. providing the same information through sound and haptics for example, was considered a potentially positive feature.

4.2 Evaluation sessions

Main takeaways from evaluation stages can be found in [17], while detailed descriptions of results for HERAKOI/EDUKOI and STRAUSS are reported below.

1. EDUKOI. The group decided that the evaluation would test the combination of audio and haptics (multimodality). The main experiment aimed to compare different tactile supports (e.g. 3D maps, frame, etc.) given a specific sonification. A pre-study was conceived to establish the most effective sonification to be used: this would involve comparing sonifications based on synthetic, musical and natural sounds. Image brightness would be sonified to provide a sense of morphology. The group stated the following hypothesis: *"Haptic displays can support the interaction with EDUKOI, helping orientation within the image and image formation"*. BVI students (9-14 years old) were chosen to be the subjects of the evaluation. Independent and dependent variables were identified correctly. The test would measure pleasantness/comfort; navigation (through location of features); orientation (through repetitively finding a feature); image formation (through image description). The procedure was described in detail. The group did not choose explicitly among the experimental paradigms provided. Finally, the group did not offer much detail on the format and analysis of the expected results.

2. STRAUSS. The group aimed to test the interactive and multimodal (audio, visual) exploration of a "spectral data cube" (a particular type of astronomy data). The test subjects would be sighted astronomers, researchers, or students, who have not used this data extensively, but have been trained to explore it visually. Efficiency would be tested by measuring speed and identification task's accuracy, i.e. correctly finding a galaxy's major rotation axes in a raw data cube. User experience would be measured through ratings of pleasantness, engagement, and fatigue. The hypothesis would be that *"the audio-visual condition is better (in terms of efficiency and user experience) than audio-only or visual-only conditions"*. The group wondered whether the most pleasant sonification would also be the most efficient. They realized that different sonification approaches should be tested, but did not expand much on this. During the test, data navigation would be performed through the trackpad or mouse. Independent and dependent variables were correctly identified. Regarding the stimuli, real astronomy data would be used as subjects are meant to be familiar with it. Prior to the test, there would be a training session. It is not clear if this was considered to help compensating for the unequal experience in using the auditory condition. The test should not last more than 1 hour and should take place in a controlled environment. They would use a within-subject design. The procedure would be optimized through a pilot. A final questionnaire should include free-text questions to provide qualitative feedback. The results would include quantitative data such as time and errors in the identification task. The group discussed normalizing accuracy results to individual performance. While this is appropriate for time performance, it might not be meaningful for the number of errors as everybody should aim for no errors. The group discussed the importance of sample size, testing different interaction modes (e.g. zooming), and testing different sonification approaches.

5. REFLECTING ON THE OUTCOMES OF THE DESIGN AND EVALUATION SESSIONS

The Design sessions were effective in providing a cross-disciplinary platform for ideation. The Data Sonification Canvas proved to be appreciated by participants and highly useful in facilitating the collaborative ideation of new sonification features for existing tools. While the resources provided helped the development of a common language, some participants found some of the terminology challenging. With regard to design choices, there was a tendency among the groups to favor iconic/analogical mappings. The Evaluation sessions were a particularly novel aspect of this workshop. They provided time for the groups to reflect on the most important characteristics to evaluate and on appropriate experimental designs. Results were encouraging, but also mixed since the degree of precision of the produced protocols varied across groups. Only one out of six original groups attempted to implement an experiment design. It is likely that more time is needed for this type of session to allow for more exploration with the concepts and terminology, and to bring all participants to the same level of understanding. A positive outcome was that all groups could reflect on the importance of measuring both objective and subjective aspects of a sonification tool.

6. DEVELOPMENT OF EDUKOI AND STRAUSS

This section traces the impact of the AU2 workshop on the development of two tools: STRAUSS and EDUKOI. Two rounds of semi-structured interviews were conducted with contributing researchers. They took place via Zoom in December 2023 (mean duration 1 hour) and by email in March 2025. A first set of questions (1-10) were asked in Zoom-interviews and were sent in advance of the meeting. A second set of questions (11-20) were updated/reformulated and sent as email-interviews. The questions were:

(1)(11) What has happened in the world of EDUKOI/STRAUSS since January 2023 (since January 2024)? (2)(12) During the AU2 workshop you discussed ideas for improving the *Interactivity* and *Multimodality*, what new features were implemented since then (since we last spoke)? (3)(13) Was there something that you attempted, but could not implement? (4)(14) Can you tell us about any challenges encountered? (5)(15) What new development are planned for the future? (6)(16) Did you develop any (How did you continue the) evaluation of the software or the new features? (7)(17) During the development of the software, did you use any of the tools (e.g. sonification canvas, evaluation paradigms) introduced to you during the workshop? (8) What were useful/not useful aspects of the design/evaluation sessions? (9) If you were to participate to similar sessions again, what adjustments would you propose? (10)(20) Is there anything you would like to add?

6.1 Interviews with EDUKOI researchers

EDUKOI is developed in the context of an interdisciplinary project led by an astronomer and a psychologist (ED1), involving a doctoral student (ED2), and two software developers. The two interviews (Zoom/2023, email/2025) with ED1 and ED2 are summarized below.

December 2023. EDUKOI is an educational application to explore astronomical images in an interactive, multimodal manner and through iconic/analogical sonification mappings. The target audience is young students. The idea of EDUKOI originated during the AU2 workshop. In the interview, ED2 mentioned that the reason why EDUKOI started to really diverge from HERAKOI was because of the different target audience, i.e. sighted and BVI school students, and purpose, i.e. exploration of astronomical images. Since AU2, EDUKOI developers implemented features discussed during the design sessions. These include a new, simple and iconic sonification of the RGB colors. The colour red is associated with the sound of fire, green with the sound of rustling leaves and birds, and blue with bubbling water. Additionally, a sound signal has been added to alert when users (in particular BVI students) are out-of-frame. Helpfully, these changes allowed to reduce the time needed to become familiar with the software and sonification, making it more intuitive and immediate. In 2023, the team performed an evaluation with a large number of school children (10-13 years old) in the context of STEM lessons. All children but one were sighted, therefore to specifically evaluate the audio-only condition the visual interface was obscured during the test. Results on the recognition of color and galaxy shapes were encouraging. Planned future developments include the addition of tactile supports (frames, 3D maps); providing the sonification of complex colors; testing a variety of image explorations approaches (e.g. free versus prescribed scanning of images). ED2 mentioned that the workshop evaluation sessions provided a very clear summary of standard paradigms useful for evaluating interactive sonification. ED1 mentioned that the experience of running a test in a complex context such as a school revealed the importance of designing with software portability in mind, as time cannot be lost for installation or problems with the local computer system. The AU2 workshop highlighted for both interviewees the interdisciplinary nature of sonification projects. The resources provided and the unique access to a network of interdisciplinary experts were considered particularly useful gains from the workshop, particularly for new researchers entering the field.

March 2025. Due to the lack of funding, new features were not developed since January 2024, however the team is planning a tablet version of EDUKOI. This would be tangible progress towards accessibility, allowing users to explore a finite surface, with the addition of tactile features such as vibration as an exploration cue. The second priority is to develop a stable version that can be easily downloaded and installed on any operating system. This would simplify evaluation in real-world contexts. Finally, the team aims to develop more complex sonification mappings as the current RGB mapping is limited when attempting to display several colours. Including electronic sounds, or filters, could better represent colour characteristics such as saturation. The intention is to continue to evaluate and develop EDUKOI through iteration and user-feedback collected in real-world contexts such as Science Festivals, schools and directly with BVI people. AU2 tools such as the Sonification Canvas were very useful and greatly used in the past, and the team intends to continue to use them in the future.

6.2 Interviews with STRAUSS researchers

Since March 2023, a 3-year project funded by the UK Science and Technology Facilities Council has supported the development of STRAUSS. This section summarises two interviews (Zoom/2023, email/2025) with the project lead and astronomer (ST1). The team also comprises a part-time research software engineer and a visually impaired astronomer.

December 2023. Several ideas discussed during the design and evaluation sessions have entered the development of STRAUSS. In 2023 the focus was the development of a "hyperspectral data listener". This is a multimodal, interactive display of a "data cube" or "hyperspectral data" in which each pixel represents a light spectrum. Through an iconic/analogical sonification, light spectra are mapped to sound spectra. Narrow emission lines are mapped to sound partials, and broad signals to noise components. This is perceived to be an intuitive data-to-sound mapping as it leverages on how the brain automatically segregates pitched and noisy signals, making this mapping coherent with the way people hear sound. Overall, ST1 thought of this approach (an idea refined during AU2) as an "elegant solution" that does not feel arbitrary. In the future, the team would like to implement additional interaction (zooming, scanning) with this audiovisual display. During AU2, in discussion with the team developing HERAKOI, ST1 realized the importance of being able to perceive the detail, pixel-by-pixel, in context. In the 2023 iteration of STRAUSS, this could not be done in real-time, but different sonified "views" at different scales could be created off-line so that they could be tested. Before the AU2 workshop, ST1 was skeptical about sonification, but since then he realized that interactivity could solve how sonification detail and overview could be accessed rapidly. Furthermore, the necessity of developing audio captioning became clear. Multimodality, and specifically haptics, emerged as a way to provide further understanding of where one is in the dataset. For this aspect, the team aims to collaborate with the "Tactile Universe" project conducted by astronomer Nic Bonne. Ways of monitoring large amounts of data is another area for future development. In regards to evaluation, for ST1 the most important takeaway from AU2 was in relation to ways to measure user experience. As a scientist, ST1 was already familiar with methods to quantitatively measure a system performance, and becoming aware of ways to test aspects such as user satisfaction, fatigue, and learning was very useful. The workshop also revealed the importance of defining the target audience and the purpose of the application. The developments of STRAUSS are about enhancing the exploration and analysis of the data for everyone, not only for BVI users. ST1 states: *"If we can manage to do this, the contribution to knowledge would have more wide-reaching benefits"*. Moreover, the STRAUSS project aims to utilize citizen science platforms, such as Galaxy Zoo or Zooniverse, to let many thousands of people evaluate astronomical sonifications, a way also to popularize the approach. The hope is that through listening perhaps new galaxy classifications could emerge. For ST1, AU2 tools such as the Sonification Canvas were very useful to understand where the STRAUSS sits in terms of design approach and purpose. The summary of experimental paradigms and discussions during activities highlighted the importance of gathering knowledge about both subjective and objective aspects. ST1 found the multidisciplinary expertise present at the workshop very fruitful. The most important aspects mentioned were: creating unique opportunities for knowledge exchange (e.g. special sessions on astronomical sonification have been created in 2023 and 2024 at a number of audio and astronomy conferences), fostering the development of a common language, and developing a network of diverse experts.

March 2025. Since January 2024, the team developed the sonification of "hyperspectral data" further by developing a "Fast Specralisation" feature, which allows to efficiently generate sounds from input spectra. STRAUSS has been integrated into the "NASA-STSci Jdviz" tool, which is used as the native data explorer for space telescope data. Through this integration, an "interactive listener" functionality for hyperspectral data was implemented, which allows to listen for spectral features such as emission lines. The implementation of real-time sonified data streams alongside pre-rendered sonified data remains a challenge yet to be resolved. Additionally, more generic interactive tools for exploring galaxy images while hearing physical properties are in development (these originated at the *Hack Days* at the ESTEC Astronomy Conference in Madrid 2024). In terms of multimodality, a STRAUSS video pipeline for combining visual animation with sonified plots has been developed. Additionally examples of sound-light data displays using LEDs were created. Other features include audio captioning and Text-to-Speech Support, which allows embedded audio captions to be written as text and heard as speech, providing context for sonifications in multiple languages. Evaluation of software and features has been primarily in collaboration with code users and through workshops at a number of conferences and institute visits, rather than with communities of users. The team is focussing on growing usership to a level where crowd-sourced feedback can be gathered for new features, and they see simplifying the user experience for first-time users as an important step. Finally, AU2 tools such as the Sonification Canvas and sound/listening concepts continue to shape and be used in the development of new features.

7. REFLECTING ON THE IMPACT OF THE AU2 WORKSHOP ON THE DEVELOPMENT OF TWO SONIFICATION TOOLS

The workshop's structure and focus on existing astronomy software applications, coupled with the active participation of their developers, enables an examination of whether the ideas generated during the event were subsequently developed, and whether the proposed approaches and tools were helpful in the process. The interviews with researchers working with two tools (EDUKOI and STRAUSS) are encouraging in regard to the impact that the workshop has had in pushing forward the development of these applications. Many ideas originated in the workshop were taken up for development. The entire concept of EDUKOI was developed at the AU2 workshop. Initially based on HERAKOI, a software for navigating any image with sound, EDUKOI is now a specialised application focusing on astronomy images and with the aim to facilitate the engagement of BVI young students with science. Discussions at the workshop provided the seed for more intuitive sonifications based on colour-sound associations, for considering haptics as a way to help navigation and meaning making, and for testing the application with the target audience and in context. Overall, researchers have embraced the importance of evaluation in sonification design, making it a crucial step within the development process. In the case of STRAUSS, ideas originated during the workshop have been implemented and partially evaluated. The workshop provided the developer with clarifications regarding doubts about sonification as a display. Three main takeaway stemmed from discussions with sound, design and HCI experts. These were: (1) interactivity can provide a way to efficiently move between different data perspectives; (2) sonifications, to be effective, need to be informed by knowledge on sound perception; and (3) purpose and target audience need to be established from the start to inform both development and evaluation, which should not only assess objective aspects but also user experience and satisfaction. All interviewees have stated that the tools provided (videos, lectures, canvas, paradigms) constitute a useful resource for development. In regard to designing evaluations, it should be noted that in both cases the interviewees had prior experience with testing procedures (in their own areas of expertise). This facilitated their ability to implement evaluations rapidly after the workshop. We observe that other participants, less experienced in testing methods, would benefit from longer evaluation sessions with examples of testing procedures that they can easily try out, and from the possibility to critically evaluate the benefits and limitations of each paradigm. Finally, the workshop allowed us to create an interdisciplinary network of experts-in sonification and astronomy-that has become a key resource in itself, since participants can now easily call upon a specialised expert for further advice and discussion.

8. CONCLUSION

This paper presented an in-depth analysis of materials produced in the AU2 workshop. These were supplemented by follow-up interviews with developers. We show that the AU2 workshop impacted the development of sonification tools. Design ideas have begun to be implemented and evaluated. Finally, we provide suggestions on how the evaluation sessions could be further refined in the future.

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