PROCEEDINGS OF SCIENCE

Art and Astrophysics in Conversation with KM3NeT Deep in the Mediterranean Sea

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We present the result of a cross-disciplinary collaboration between Donald Fortescue of the California College of the Arts in San Francisco and researchers from the KM3NeT Collaboration. The project involved creating an analog sound producing instrument which was installed within a standard KM3NeT pressure resistant glass sphere housing along with sound and video recording equipment. The instrument, titled "Bathysphere", was deployed in the sea for the first time adjacent to the ORCA array of KM3NeT off the coast of France on September 23, 2021.
One outcome of this project is the video work "Below the Surface". It incorporates sound and video recorded from within the "Bathysphere" as it floated on the surface of the Mediterranean and then as it dived down to 300m depth. As the "Bathysphere" dived, the analog instrument it contained quietened. The sound in the dive portion of the video is created from the sonification of data from the KM3NeT array that was recorded during the deployment of the "Bathysphere".
"Below the Surface" highlights the extraordinary environment in which the KM3NeT array is being created and operates. The data sonification illustrates the potential of this method of data representation to connect with viewers in a deeply physical way and offers new perspectives on the data collected by KM3NeT.

38th International Cosmic Ray Conference (ICRC2023)
26 July - 3 August, 2023
Nagoya, Japan

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PoS(ICRC2023)1621

1. Introduction

We present the result of a cross-disciplinary collaboration between Donald Fortescue and researchers from the KM3NeT Collaboration [1]. The project builds on the successful art/science research collaboration between Fortescue and De Wasseige, initiated during Fortescue's US National Science Foundation funded residency with the IceCube Neutrino Observatory [2] at the South Pole in the austral summer of 2016/17. The outcomes of this previous collaboration were presented at the 36th International Cosmic Ray Conference (ICRC2019), in Madison and were detailed in the proceedings of that conference [3].

KM3NeT is a European particle astrophysics research infrastructure located at several sites deep in the Mediterranean Sea, illustrated in Fig. 1. When fully completed, KM3NeT will search for neutrinos from distant astrophysical sources like supernova remnants, gamma-ray bursts, supernovae or colliding stars and will be a powerful tool in the search for dark matter in the universe. It also houses instrumentation for monitoring the deep-sea environment used by other sciences such as marine biology, oceanography and geophysics. KM3NeT consists of two discrete detector arrays: ORCA situated off the coast of Marseille, France, and ARCA situated off the coast of Sicily, Italy.

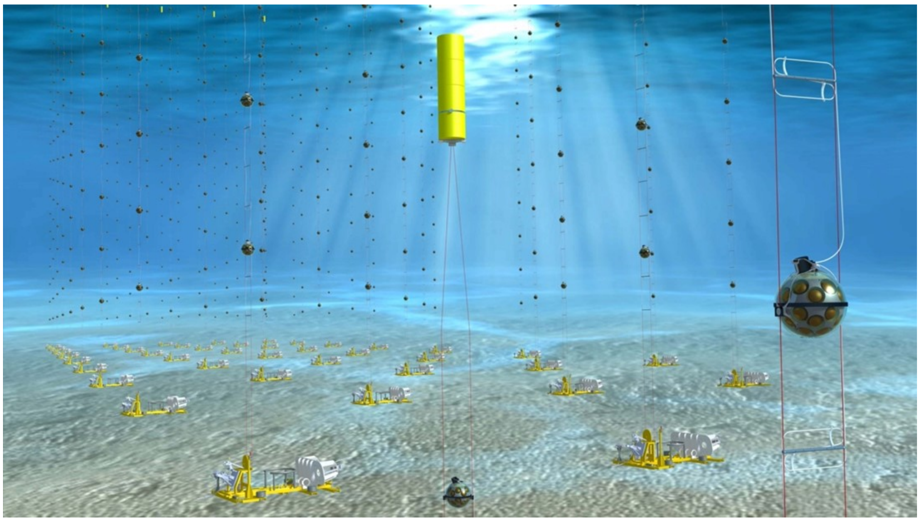

Figure 1: Artist's Rendering of the ORCA Array.

The current project involved Fortescue creating an analog, sound producing, instrument which was installed within a standard KM3NeT pressure resistant glass sphere housing along with sound and video recording equipment. This instrument, titled "Bathysphere"[1], was deployed for the first time, adjacent to the ORCA array of KM3NeT, off the coast of Marseilles, on September 23, 2021.

One outcome of this project is the video work "Below the Surface". The work incorporates sound and video recorded from within the "Bathysphere" as it floated on the surface and as it dived down to 300 m depth. As the "Bathysphere" dived, the analog instrument it contained quietened. The sound in the dive portion of the video was created from the sonification of data from the ORCA

[1]Named in honor of the Bathysphere developed by Otis Barton and deployed by Barton and William Beebe during the first deep-water dives in Bermuda in the early 1930's.

array that was captured during the dive of the “Bathysphere”. "Below the Surface" is publicly available at https://vimeo.com/844369324

2. Process

2.1 The Bathysphere

Figure 2: The “Bathysphere” internal mechanism.

The completed “Bathysphere” is an idiophonic instrument that operates on the surface and at depth to transduce water oscillations into sound. The analog, sound producing component of the bathysphere consists of seven, concentric, stainless steel, hemispheric bells attached to a central axis. These bells are activated by six stainless steel hammers which are free to rotate around the central axis, as shown in Fig. 2. Sounds are produced by the hammers hitting the bells and by them running around the rim of the bells, much like the action employed in the playing of Himalayan prayer bells. A standard GoPro Hero 8 and Sony Digital Audio Recorder are attached to the upper platform of the “Bathysphere” to record video and the sound produced by the “Bathysphere”.

Deployment involved lowering the “Bathysphere” with its attached ballast weight and connected flotation buoy to the sea’s surface (Fig. 3). The flotation buoy for the ballast was connected to a line running to the deployment vessel and the “Bathysphere” was connected to another line with depth markers every 5 m. The “Bathysphere” was allowed to float on the surface some 50 m from the deployment vessel for about 15 minutes (Fig. 4), then the flotation buoy was released and retrieved back to the ship. With the release of the flotation buoy, the ballast sank and towed the “Bathysphere” along with it. Once the “Bathysphere” reached approximately 300 m depth, it was hauled back to the surface and retrieved. Three separate dives were possible during the first Mediterranean deployment of the “Bathysphere”.

Video and sound were recovered from the recorders. Recordings from the third dive were edited and used to create the video work “Below the Surface”, which incorporates both recorded “Bathysphere” sounds and sonified data from the ORCA array.

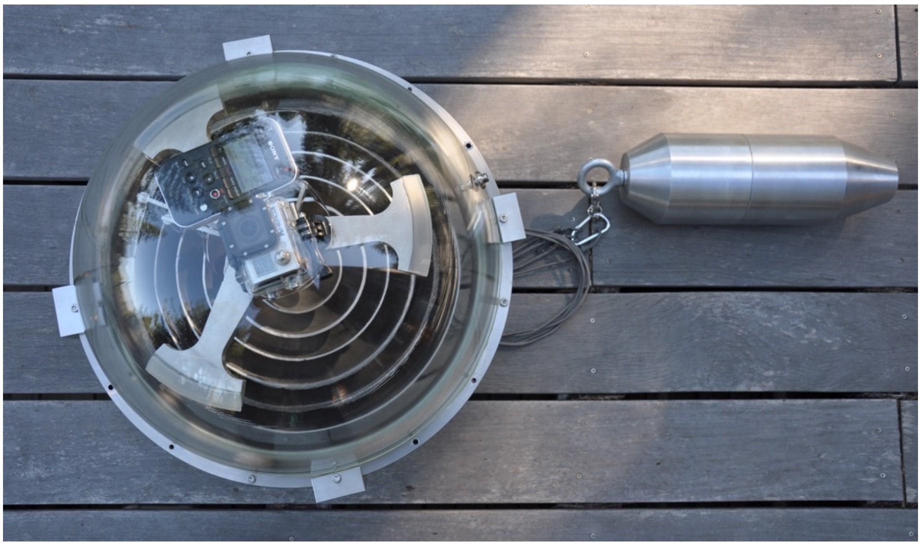

Figure 3: The “Bathysphere” ready for deployment.

2.2 Sonification

Two terms, used by both scientists and sound artists working with converting data to sound, are ’audify’ and ’sonify’. Audification is the making audible of an inaudible sound through amplification or through transposing frequencies into the range that humans can hear, this is the process that makes whale song audible to us. Audification is essentially sound transcription. Sonification is the process of rendering other forms of data into sound, e.g., electromagnetic, particle flux or gravitational wave signals. Sonification is the transduction of non-audio data into audible sound. “Below the Surface” incorporates the sonification of digital signals derived from the detection of photons by the ORCA array, deep in the in the Mediterranean Sea, into sounds we can hear.

There are innumerable ways that data can be transduced into sound. Each requires the allocation of sound frequency, volume, duration and timing values to map the event rate, deposited energy, photon flux and location values in the data. Some mappings are readily suggested by the shared characteristics of sound and light waves, such as frequency, intensity, and duration. Others, such as which events are sampled, the sampling rate and playback speed, need to be selected to both reflect the underlying physics and to satisfy aesthetic considerations, that is, to ensure the resulting work will be engaging. As well, the mode or “instrument” chosen to play the sounds is open for creative interpretation. We selected a digital instrument based on the glockenspiel for the “Below the Surface” sonification as it was a close analog to the sounds produced by the “Bathysphere”.

During the “Bathysphere” deployment, six Detection Units (DU) were active in the ORCA array. Currently, there are 18 operational DUs after three successful deployments since 2022. Each DU holds 18 Digital Optical Modules (DOMs) and each DOM houses 31 Photomultiplier Tubes (PMTs) [4].

The sonification process we developed involved assigning four discrete notes to each DOM by dividing each DOM into four regions (upper, mid-north, mid-south, and lower), each with either 8 or 7 PMTs. Each region was assigned a note so that groups of three adjacent DOMs on the same DU cover one octave on the chromatic scale. Within each octave, individual DOMs have been tuned to avoid strong dissonances in adjacent groups. This was done because luminous events happening close to a DOM will likely be detected by multiple PMTs belonging to different groups. Without appropriate tuning, strong dissonances would characterise the overall sound of the track as an artifact of the grouping of PMTs. In a manner similar to tuning a musical instrument, each of the three DOM has been given a unique sound given by the choice of the four notes that it covers.

The four-note groups for each of the three DOMs that form an octave are as follows (in the order: upper, mid-north, mid-south, lower): (1) B, E, G, C; (2) F, Bb, Eb, Gb; (3) Ab, Db, D, A.

Each DU has a range of 6 octaves, going from C1 to B6. Lower octaves are mapped to the bottom of the detector, while higher octaves are found at the top. This allows us to reproduce the dimensionality of the detector and the geometrical distribution of the sonified signal. A filter was used at the DOM level on low level data from the detector. A cut on the minimum cumulative charge detected by signals in coincidences of 100 ns on the same DOM was applied to get rid of most of the random coincidences caused by incoherent noise and to focus more on coherent environmental and atmospheric activities. These signals are expected to be produced by the decay of sea salt (^{40}K), and from bioluminescent species (fish and plankton), as well as Cherenkov photons from the interaction of atmospheric muons and neutrinos. The detected charge is used to modulate the volume of the notes, such that higher charge corresponds to a louder volume. The timing of detection is scaled and directly mapped onto the timing of the notes in the track, coincident notes with the same pitch coming from the same DOM are merged into a single note with volume level given by the sum of the original volumes.

The data that we selected for the sonification came from the duration of the dive that was recorded and edited for the video portion of this project The video “Below the Surface” is 6 minutes and 6 seconds long (6:06), and is played on a continuous loop. The dive portion of the video runs for 4 minutes and 40 seconds. The “Bathysphere” was underwater for exactly 30 minutes (1800 seconds) during its third dive. To produce the track in “Below the Surface” around 0.4 seconds of data were used, starting from September 23rd, 2021, 16:34:00 UTC, which coincides with the time the “Bathysphere” reached its maximum depth during the dive.

3. Outcomes and Perspectives

“Below the Surface” was shown for the first time at ICRC2023. It will be presented at both science and art venues in Australia, the USA, and Europe over the coming months and years. It will bring awareness of the research of the KM3NeT Collaboration to new audiences and provide an original perspective on leading astrophysical research, which can be difficult for lay audiences to engage with.

Figure 4: The "Bathysphere" submerged.

Cutting-edge contemporary astrophysical research instruments, like KM3NeT, are often located in challenging and inaccessible locations, such as the Antarctic, the high deserts of South America, deep in the waters of the Mediterranean Sea and Lake Baikal. The locations in themselves are sources of wonder. "Below the Surface" aims to highlight the extraordinary collaborative effort and technology required to create a complex instrument to be deployed deep in the ocean, as well as the unique natural environment in which it is located.

The craftsmanship involved in creating the unique, specifically designed and calibrated, analog instrument contained within the "Bathysphere" echoes the incredible technical craftsmanship that has been developed for and is continuing to evolve as the deep-sea array of KM3NeT is created and deployed. This technical ingenuity and sophisticated craftsmanship is often overlooked by the wider public and in the case of neutrino telescopes is hidden in the vast, inaccessible natural spaces in which they are deployed.

3.1 Objective approaches to art making

Viewers may assume that the underwater audio for "Below the Surface" was composed specifically for the video. In a sense it was, but the individual notes and their timing were not selected by the work's authors. Instead, it was established an objective set of constraints on the data set selected and the way this data was then transduced into sound. This is analogous to the way a scientific study uses a blind procedure, that is, developing the analysis on sample data, selecting relevant 'signal' data and then processing that data for final analysis. Such an objective approach to art making might, at first glance, seem to deny the creativity of the artist. However, this approach has a strong precedent in contemporary art. An objective methodology where distinct rules are established to constrain artists' choices was first established by the minimalist and conceptual artists of the 1960's and 70's who were striving to reduce artistic agency in reaction to the dominant paradigm of Abstract Expressionism. The renowned conceptual artist Sol LeWitt explained in his Paragraphs

Figure 5: The team who participated in the successful deployment of the "Bathysphere". From L to R. Prof. Donald Fortescue, Prof. Gwenhaël De Wasseige, Dr. Vincent Bertin, Conrad Bertrand, Alexandre Cornillon, Alin Ilioni, and (foreground) Dr. Paschal Coyle

on Conceptual Art: *"To work with a plan that is preset is one way of avoiding subjectivity. It also obviates the necessity of designing each work in turn. The plan would design the work. Some plans would require millions of variations, and some a limited number, but both are finite. ... In each case, ... the artist would select the basic form and rules that would govern the solution of the problem. After that the fewer decisions made in the course of completing the work, the better. This eliminates the arbitrary, the capricious, and the subjective as much as possible" [5].*

The objective approach provides a strong link between the methodological practices of science and art and can help delineate the required conditions for effective art/science collaborations, that is, the common ground where the two methodologies may coalesce.

3.2 Value of sonification

Sonification is a methodology that is generating wide interest in contemporary data science, and for this there are several reasons. We readily discern sound as occurring in three dimensions, so it would seem that 'listening' to data that derives from interactions across three-dimensional space could be more intuitively informative than 'looking' at graphic analysis or animated renderings on a 2D screen. Also, sonification permits access to data sets by researchers for whom vision might not be their primary sense, thus enabling a broader diversity of scientific researchers. And finally, more general audiences have a direct visceral connection to sound which can facilitate a deeper direct connection with the phenomena being studied by leading research institutions.

3.3 Collaboration

Artists are rarely considered key components of collaborative science research teams. They are often seen as addenda to the core science, as illustrators or designers who can help with posters or presentations for public outreach. The durable art/science collaboration developed by the authors over many years provides a model for imbedding artists within science teams to facilitate new perspectives and audiences.

As the KM3NeT array is still under development, the current collaboration provides the potential for ongoing art/science projects as the one described in these proceedings (Fig. 5). For example, future sonified works from the array could become more richly complex. The sonification for "Below the Surface" could be considered as just one instrument playing a motif that has the potential to grow into a full orchestral work, over time, as the array attains its full functionality.

4. Conclusions

"Below the Surface" highlights the extraordinary environment in which the KM3NeT array is being created and operates. The craftsmanship of the "Bathysphere" echoes the technical sophistication of the unique instrumentation of KM3NeT. The data sonification created for "Below the Surface" illustrates the potential of this method of data representation to connect with viewers in a deeply physical way and offers new perspectives on the data collected by KM3NeT. The durable art/science collaboration developed by the authors over many years provides a successful model for imbedding artists within science teams to facilitate new perspectives and audiences.

Acknowledgements

Special thanks to Dr. Véronique Van Elewyck, Lawrence LaBianca, Paolo Salvagione, and Dr. Sandra Kelch for assistance with the development of the "Bathysphere". Thanks, are also due to the other team members who so generously contributed to the successful deployment of the "Bathysphere" in September 2021 - Dr. Vincent Bertin, and Conrad Bertrand and Alexandre Cornillon aboard the MV Foselev Onyx. Fortescue's research is supported by the California College of the Arts and by KM3NeT. Fortescue and De Wasseige received a Materials Based Research Grant from the Center for Contemporary Craft in Asheville NC, USA to develop this project. The data used was generously provided by and used with the permission of the KM3NeT Collaboration.

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Acknowledgements for the KM3NeT Collaboration

The authors acknowledge the financial support of the funding agencies: Agence Nationale de la Recherche (contract ANR-15-CE31-0020), Centre National de la Recherche Scientifique (CNRS), Commission Européenne (FEDER fund and Marie Curie Program), LabEx UnivEarthS (ANR-10-LABX-0023 and ANR-18-IDEX-0001), Paris Île-de-France Region, France; Shota Rustaveli National Science Foundation of Georgia (SRNSFG, FR-22-13708), Georgia; The General Secretariat of Research and Innovation (GSRI), Greece Istituto Nazionale di Fisica Nucleare (INFN), Ministero dell'Università e della Ricerca (MIUR), PRIN 2017 program (Grant NAT-NET 2017W4HA7S) Italy; Ministry of Higher Education, Scientific Research and Innovation, Morocco, and the Arab Fund for Economic and Social Development, Kuwait; Nederlandse organisatie voor Wetenschappelijk Onderzoek (NWO), the Netherlands; The National Science Centre, Poland (2021/41/N/ST2/01177); The grant "AstroCeNT: Particle Astrophysics Science and Technology Centre", carried out within the International Research Agendas programme of the Foundation for Polish Science financed by the European Union under the European Regional Development Fund; National Authority for Scientific Research (ANCS), Romania; Grants PID2021-124591NB-C41, -C42, -C43 funded by MCIN/AEI/ 10.13039/501100011033 and, as appropriate, by "ERDF A way of making Europe", by the "European Union" or by the "European Union NextGenerationEU/PRTR", Programa de Planes Complementarios I+D+I (refs. ASFAE/2022/023, ASFAE/2022/014), Programa Prometeo (PROMETEO/2020/019) and GenT (refs. CIDEGENT/2018/034, /2019/043, /2020/049. /2021/23) of the Generalitat Valenciana, Junta de Andalucía (ref. SOMM17/6104/UGR, P18-FR-5057), EU: MSC program (ref. 101025085), Programa María Zambrano (Spanish Ministry of Universities, funded by the European Union, NextGenerationEU), Spain; The European Union's Horizon 2020 Research and Innovation Programme (ChETEC-INFRA - Project no. 101008324); Fonds de la Recherche Scientifique - FNRS, Belgium.

PoS(ICRC2023)1621