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III Workshop for Astronomy Beyond the Common Senses for Accessibility and Inclusion (3WAI) (November 29-30, 2023)
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THE DISCOVERY OF UCAC4 459-092739 BY BLIND AND VISUALLY IMPAIRED STUDENTS: LISTENING TO THE STARS

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RESUMEN

La astronomía es uno de los temas más interesantes a la hora de fomentar las vocaciones STEAM entre los estudiantes de Primaria y Secundaria por su naturaleza interdisciplinar. Sin embargo, esta disciplina es principalmente visual, quedando a veces el alumnado ciego o con discapacidad visual (BVI) excluidos de los proyectos de fomento de las vocaciones STEAM. La sonificación (el uso de sonido para representar datos y conceptos) puede ser una herramienta útil para la inclusión del alumnado BVI en los proyectos educativos astronómicos. Durante el curso 2021-2022 organizamos dos talleres sobre sonificación científica para seis estudiantes BVI del sistema educativo público de las Islas Canarias (España). Como resultado de estos talleres, los participantes se convirtieron en los primeros estudiantes BVI de la historia en descubrir una estrella variable, UCAC4 459-092739. Así, hemos demostrado que los estudiantes BVI pueden aprovechar la sonificación para mejorar su capacidad de analizar datos reales e, incluso, hacer ciencia real.

ABSTRACT

Astronomy is one of the richest topics available to foster STEAM vocations among our Primary and Secondary Education pupils due to its inspiring and interdisciplinary nature. However, astronomy is a predominantly visual discipline and blind and visually impaired (BVI) students are often excluded from the projects designed to foster STEAM. Sonification (using sound to represent data and concepts) can be a useful tool to engage BVI students in astronomical educational projects. Following this idea, we organized two workshops during the academic year 2021-2022 school term on scientific sonification for six BVI students of the Public Education System from the Canary Islands (Spain). As a result of these workshops, the participants became the first BVI students in history to discover a variable star, UCAC4 459-092739. Thus, we have shown that BVI students may take advantage of the interactive and exploratory nature of sonification, extending their capacity to analyze real life datasets or, even, doing real Science.

Key Words: inclusive education — STEAM — variable star — blind and visually impaired — sonification

1. ASTRONOMY IN STEAM EDUCATION

It is widely known that astronomy is one of the richest topics available to foster Science, Technology, Engineering, Arts and Mathematics (STEAM) vocations among our Primary and Secondary Education pupils due to its inspiring and interdisciplinary nature (Pasachoff 2005).

In fact, The Astronomical and Educational Association of Canary Islands "Henrietta Swan Leavitt" (AAEC) has designed, tested and coordinated four innovative projects managed by the regional Department of Education, Professional Training, Physical Activity and Sports (CEFPAFD) of Gobierno de Canarias (Canary Islands, Spain), through their Program for Fostering Scientific Vocations and Creativity (STEAM). The first of these projects started in 2019 and all of them are still going. The Canarian teachers who take part in these projects acquire the necessary skills to carry out specific scientific activities with their students using mainly the STEAM subjects and following the principle "Learn Science by doing Science". In addition, students and teachers learn to appreciate and love the night sky as a world heritage that is deeply rooted in human history.

For example, in the "Variable Stars Characterization" project, students link Secondary Education STEAM subjects contents to variable stars and its different types, photometry, period determination, Python Programming or even specialized software usage such as Aladdin, AAVSO VSTAR or

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Fotodif and how to apply this knowledge to exoplanets characterization and distance determination to other galaxies. During the 2023-2024 school term, 14 Canarian High Schools participate in this project, involving around 600 pupils. They may even discover new variable stars previously unknown to the scientific community; in fact, Canarian students, working from their classrooms and during ordinary scholar time, have discovered eight new variable stars since 2017: GSC 03224-01689[4], TYC 3224-2619-1, UCAC4 534-052935, UCAC4 722-057426, UCAC4 456-032928, GSC 01861-01621, GSC 05063-00753 and UCAC4 459-08227. All of them have been registered in the International Variable Star Index (VSX)[5], the variable stars database created by the American Association of Variable Star Observers (AAVSO)[6], a non-profit worldwide scientific and educational organization founded in 1911 to coordinate variable star observations.

On the other hand, the "Asteroid Hunters in the Canary Islands" project, not only implements the International Astronomical Search Campaign (IASC)[7] with Canarian students but link STEAM subjects contents from Primary and Secondary Education to asteroids, trajectories, Solar System bodies and Astrometrica Software. This planetary defense service-learning project has led to the discovery of more than 700 potential Near-Earth Asteroids by students[8] in the last five years. During this term, 30 Canarian Schools participate in this project, involving around 900 students.

Another worth mentioning project is "Computational Thinking and Space Sciences", which links Secondary Education STEM subjects contents to Raspberry Pi + Sense HAT IoT capabilities, Python Programming techniques, Data Science and Machine Learning in the context of the Astro PI Mission Zero and Astro Pi Mission SpaceLab Competition of the European Space Agency (ESA)[9]. As a result, Canarias1 Team, a group of six students from El Calero High School (Gran Canaria, Spain) won the Astro PI Challenge in 2017-2018[10], where they calculated the ISS speed by means of the mathematical analysis of temperature time series and built a 3D map ot the Magnetic Field Intensity around The Earth; and Rocha21, a second group of students from José Frugoni Pérez High School, was chosen as a Highly Commended Team by ESA in Astro PI Challenge Competition 2021-2022 for using SonoUno software (Casado et al., 2019) and online Braille translators to design tactile diagrams in order to explore Life on Earth photographs and NDVI data[11]. During 2023-2024 school term, 12 Canarian High Schools participate in this project, involving around 400 pupils.

Finally, The "Astronomy, Woman and Poetry" project offers Canarian students the possibility of learning astronomy through an innovative and holistic approach that promotes critical thinking, creativity and artistic sensitivity. The main objective of the project is to promote, through astronomy, scientific and humanistic vocations in an inclusive way, especially among girls, taking into account a gender perspective. A key aspect of the initiative is the collaboration with female voices of Canarian and Latin American poetry, such as Barreiro-Llorente, Teca; Marrero-Berbel, María del Pino; Molina-Rodríguez, Josefa and Reina-Jiménez, María del Carmen among others, whose productions involve different astronomical topics. During 2023-2024 school term, 20 Canarian high schools participate in this project, involving around 600 pupils

As a summary, AAEC "Henrietta Swan Leavitt" has designed and coordinated four STEAM projects aimed at Primary and Secondary Education students in collaboration with the regional Department of Education, Professional Training, Physical Activity and Sports (CEFPAFD) of Gobierno de Canarias, through their Program for Fostering Scientific Vocations and Creativity (STEAM) with the common denominator of "Learning Science by doing Science". As a drawback, these projects were not originally designed taking into account blind and visually impaired (BVI) students.

2. ASTRONOMY FOR VISUALLY IMPAIRED STUDENTS

A recent review on inclusive education of blind or visually impaired (BVI) students showed a lack of opportunities for students with visual impairment to opt for higher-level academic courses, especially in sciences (Miyauchi 2020). Authors hypothesize that one of the reasons for this could be that BVI students do not receive the same opportunities as their sighted peers to pursue certain subjects, like sciences, at advanced level.

[4] https://www.iac.es/en/outreach/news/high-school-students-canary-islands-discover-two-variable-stars-0

[5] https://www.aavso.org/vsx/index.php

[6] https://www.aavso.org/

[7] http://iasc.cosmosearch.org/

[8] https://astronomiayeducacion.org/wp-content/uploads/2023/12/LPR_Diario_20231221-Pagina-1-General.pdf

[9] https://astro-pi.org/

[10] https://www.esa.int/Education/AstroPI/European_Astro_Pi_Challenge_Mission_Space_Lab_winners

[11] https://www.esa.int/Education/AstroPI/Astro_Pi_Mission_Space_Lab_2021_22_The_Winners

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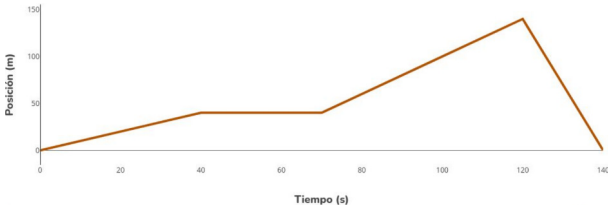

Fig. 1. Design of a piecewise function on a handmade tactile diagram representing the position of an object, in meters, as a function of elapsed time, in seconds.

Astronomy is often perceived as a predominantly visual discipline, which can create barriers for BVI students. But this visual predominance is more a historical reason than a real need. In a recent interview with BVI researchers on Nature Astronomy (Noel-Storr & Willebrands 2022), the use of images as the only way to teach astronomy was considered as "lazy teaching", and the interviewees proposed a multimodal approach, including tactile and audio tools, to investigate and teach in the field of astronomy.

There is evidence that Interactive e-learning with audio and touch-based assistive technologies are potential tools to enhance good mathematical skills in BVI students (Klingenberg et al., 2020). Sonification, a technique that consists of using sound to represent data and concepts, has been used (Diaz-Merced et al., 2011) for BVI researchers in the field of astronomy. Thus, it was decided that sonification could be a useful tool to engage BVI students in astronomical educational projects.

3. WORKSHOPS ON SONIFICATION AND ASTRONOMY

The Astronomical and Educational Association of the Canary Islands "Henrietta Swan Leavitt", in collaboration with the STEAM Program and the department for Specific Educational Support Needs (NEAE) of CEFPAFD of Gobierno de Canarias, organized two workshops during the 2021-2022 school term on scientific sonification for six BVI students of the Canarian Public Education System.

The first workshop[12], celebrated on April 19, 2022, in Las Palmas de Gran Canaria Teacher Training Center, was designed to familiarize students with this new technique. To achieve this, a set of mathematical graphs representing both theoretical and diverse situations in real contexts were sequentially sonified in increasing order of difficulty. Each graph was sonified using SonoUno software a total of three

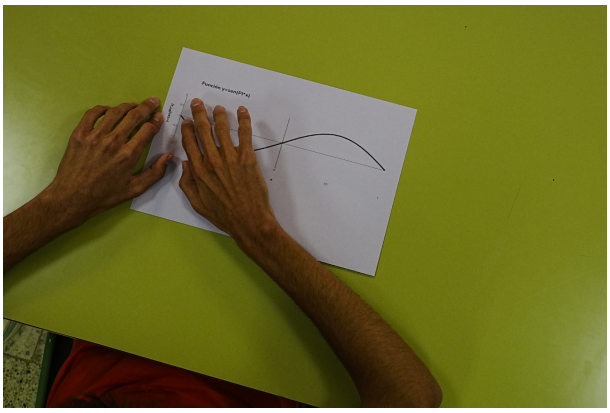

Fig. 2. Visually impaired student interpreting a sinusoidal function through both sound and its corresponding handmade tactile diagram.

times, the first two for students to try to interpret them uniquely through sound. Following this, a discussion time was established between the students and the staff of the AAEC, mostly Primary and Secondary Education teachers, who guided them in analyzing and recognizing the most significant and global patterns perceived in the audio.

Subsequently, the sonified audio was replayed with the assistance of the equivalent tactile diagrams distributed beforehand with descriptive Braille labels. This allowed students to follow them through touch as they listened again to the sonified audio, materializing the analyzed concepts. A total of 10 mathematical graphs were sonified, including linear, piecewise, quadratic, rational and sinusoidal functions (Figs. 1 and 2).

In the second workshop[13], held on May 17, 2022, in Las Palmas de Gran Canaria Teacher Training Center, this technique was used again with the aim of making a real scientific discovery: the identification of a new variable star not previously registered in the AAVSO VSX Database. Before this, students took part of a journey through the constellations and the Universe in the first part of the workshop accompanied by AAEC personnel as a prelude and contextualization of the research.

During this introduction, key physics concepts were explained by AAEC staff: star formation, the nature of light, luminosity and relative magnitude of a star were explained exclusively with this tactile (Fig. 3).

Afterwards, the well known Orion and Virgo constellations were explained and explored by tactile

[12] https://astronomiayeducacion.org/taller-de-introduccion-a-la-sonificacion/

[13] https://astronomiayeducacion.org/taller-2-de-sonificacion-descubriendo-el-universo/?cn-reloaded=1

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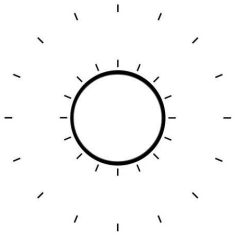

Fig. 3. Tactile diagram used to explain the nature of the light emitted by a star.

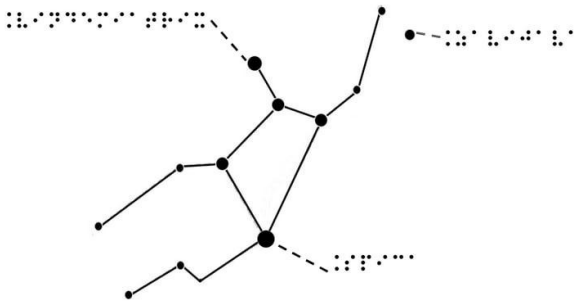

Fig. 4. Tactile diagram designed to explain the prominent stars of the Virgo Constellation with Braille labels.

diagrams including the dramatization of a Scientific-Mythological walk through the constellation of Virgo by two students from Politécnico Las Palmas High School and their AAEC teacher: the figure of the woman, including myths and legends of goddesses of justice and warrior women like Virgo, and its main star, the spectroscopic variable Spica, a binary system of fiery spikes, were evoked in the celestial dome. In addition, its role as Mother Goddess of fertility and the ancient Greek Demeter goddess of the harvests were also highlighted.

The students were also given a picture with the tactile diagram of the Virgo constellation with the more characteristic stars in Braille: Zavihava, Spica and Viendimiatrix (Fig. 4).

The concept of brightness variability was introduced with an adequate tactile diagram (Figs. 5 and 6), from which the concept of time series was generalized.

The graph of the exoplanet HAT-P-16b and the curve of a pulsating variable star (Fig. 7) were also analyzed and sonified after explaining the difference between theoretical graphs and the experimental graphs that are really obtained in real life phenomena and scientific experiments (Fig. 8).

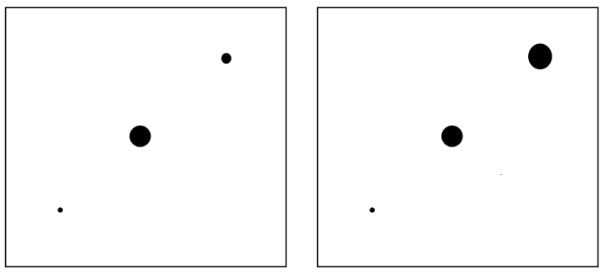

Fig. 5. Star brightness variability through time of the upper right star due to extrinsic or intrinsic reasons.

Fig. 6. Student analyzing the variation in brightness of a variable star through a previously designed tactile sheet (Fig. 5) which represented two simplified light images from the same sky field in two different times, a key step in order to generalize the concept of lightcurve and a prerequisite of the real discovery which was about to take place.

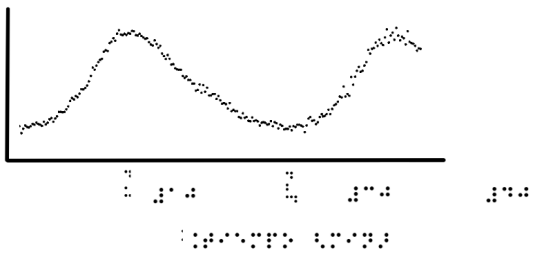

Fig. 7. Tactile diagram designed to explain the variability in brightness of a pulsating star and its corresponding physical interpretation. Afterwards, the dataset was sonified by SonoUno.

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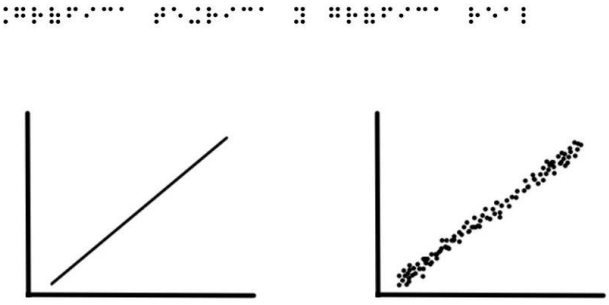

Fig. 8. Tactile diagram with Braille labels used to explain the difference between theoretical graphs commonly found in math textbooks and the actual graphs obtained in experimentation through data collection via observation. Afterwards, both datasets were sonified by SonoUno.

On the other hand, and before describing the variable star search, it is important to describe how these BVI students were also introduced into the Astro PI Challenge Competition during this second workshop. The staff of the AAEC explored the sonification technique with $\sim$ 100 sighted students, aged from 12 to 17, from September 2022 to June 2023 at the José Frugoni Pérez High School in Telde, Gran Canaria, as part of a service-learning project aimed at empathizing with BVI people, in collaboration with the Educational Assistance Team for People with Visual Disabilities of Las Palmas (EAEPDV Las Palmas) of Gobierno de Canarias.

Moreover as it has been said, a subgroup of these students, Rocha21, participated in the AstroPi Challenge competition in the Mission Space Lab category. This competition, annually organized by the European Space Agency (ESA), provides students across Europe with the opportunity to conduct scientific research using two Raspberry Pi devices located inside the International Space Station (ISS) through Python programming. This team submitted various sonification enriched scientific experiments to the competition, such as estimating the ISS speed by studying the temperature time series or applying an NDVI filter for the recognition of satellite images, including tactile sheets and sonified audios of graphs. This material was also used in this second workshop (Figs. 9, 10 and 11) with the help of Rocha21 students.

Fortunately, Rocha21 team achieved a highly favorable outcome receiving the "Highly Commended" designation, placing them among the top 16 teams out of 799 participants from across Europe, reaching an unprecedented milestone as the first team to design activities to engage BVI students in the competition.

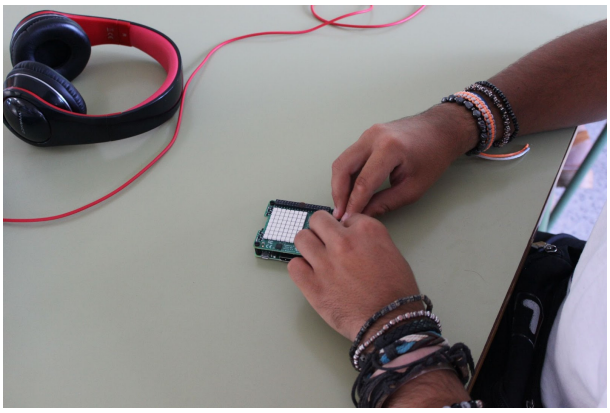

Fig. 9. One of the participating BVI students of the workshop manipulating a Raspberry Pi while the operation of this device was being explained.

Fig. 10. Tactile diagram designed to illustrate the areas where the ISS (triangle) was eclipsed or not eclipsed by planet Earth (black circle). Experiment for the estimation of the ISS velocity based on temperature.

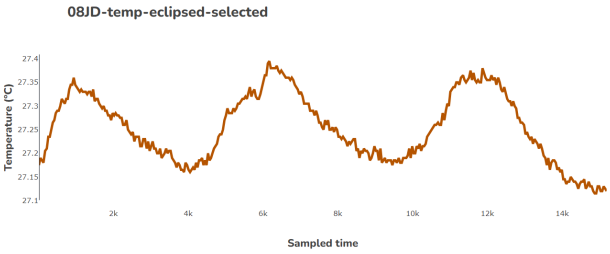

Fig. 11. Sonified graphic generated by SonoUno software depicting the evolution of the temperature obtained inside the ISS over time. The areas where the ISS was eclipsed or not by planet Earth are easily visualized, touched and sonified through the decrease or increase, respectively, in temperature. It is important to highlight that the imported data was downsampled to reduce the number of records due to limitations of the software.

4. THE DISCOVERY OF UCAC4 459-092739

As we have already explained, during the first workshop, BVI students got familiar with the sonifi-

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cation technique by means of exploring a specially designed set of mathematical functions by both, homemade tactile diagrams and their corresponding sonifications.

On the other hand, during the second workshop, and after getting in touch with astronomical concepts (light, star formation, luminosity, apparent brightness, constellation, mythology, ...), the difference between theoretical functions and real life datasets and, finally, with lightcurves; the students were challenged to do real science looking for a potential variable star.

To do so, they had to analyze each lightcurve of each star of a target sky field and look for a significant pattern out of the noise. In fact, this task is one of the phases of the "Variable Star Characterization" project yearly organized in collaboration with the regional Department of Education, Professional Training, Physical Activity and Sports (CEFPAFD) of Gobierno de Canarias, through their Program for Fostering Scientific Vocations and Creativity (STEAM).

Each lightcurve could be printed using a thermal printer, which was more expensive but faster; or just be printed with a normal one and turned into homemade tactile diagrams, which was time consuming but cheaper. Nevertheless, printing tens, hundreds or even thousands of lightcurves for each BVI student was not a sustainable option, but it was indeed the perfect issue to be solved by sonoUno sonification software.

So, we started capturing images of a target sky field (Fig. 12) and, after calibrating them, we extracted the lightcurves into csv files using Fotodif software and appropriate AAVSO comparison stars.

Once the csv files were prepared, we inverted and eroded a target sky field image using The Gimp software to reduce the number of stars from which we selected a subset of them (recommended up to 20) in order to make a tactile map of the stars to be analyzed (Fig. 13).

Each student, equipped with this tactile map, a laptop with SonoUno software and the guidance of the specialists in the team, sonified each csv file trying to detect signal out of the noise, exploring stars from A to P, discarding all non variable lightcurves (in the time span under analysis) and clearly detecting the variability of the K star (Fig. 14).

The K star, officially registered in the International VSX Database on May 27, 2022 as UCAC4 459-092739[14] and located at J2000.0 19 18 25.44 +01

[14] https://www.aavso.org/vsx/index.php?view=detail.top&oid=2227443

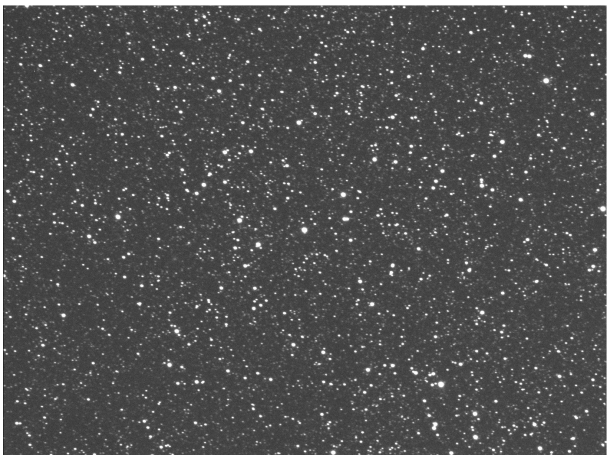

Fig. 12. Target sky field, an 40'x30' piece of Aquila Constellation centered on J2000 19:17:10.48 +01:42:38.5. Filter: V. Exposure time: 60 s. Facility: Observatorio Astronómico de Gran Canaria (J56).

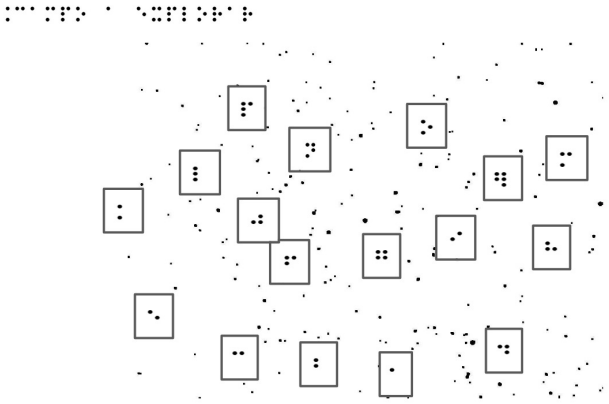

Fig. 13. Tactile map of a subset of 17 stars selected from the eroded target sky field. Each target star is next to the upper right corner of the corresponding rectangle and labeled with a letter in Spanish Braille: A, B, C, D, E, F, G, H, I, J, K, L, M, N, Ñ, O and P.

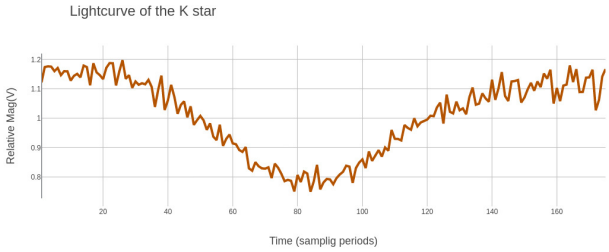

Fig. 14. Lightcurve of the K star. Time is expressed in sampling periods (64 seconds), and differential magnitude (V) is used for practical purposes.

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45 23.9, turned to be a new EA variable star with a period of 3.884624 days and, in fact, the first variable star discovered by blind and visually impaired students in history.

Congratulations to its discoverers: Alonso-Herrera, David Oriel; Bello-Uchoa, Carla; Figueroa-Franquiz, Ariana; López-Santana, Killian José; Martín-Guillén, Erika Naiara and Siverio-Sánchez, Quintín Ignacio.

5. CONCLUSIONS

It has been shown that astronomy is a perfect topic to design not only significant and exciting but inclusive projects where all the students may be involved. Teaching and learning STEAM and, in general, all mathematics related subjects, may be boosted by incorporating sonification techniques into their lessons. Thus, blind and visually impaired students may take advantage of the interactive and exploratory nature of sonification, especially with non proprietary software such as sonoUno, extending their capacity to analyze real life datasets or, even, doing real science.

Learning Science by doing Science is now possible for everybody and the discovery of UCAC4 459-092739 is a perfect proof of concept.

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