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GWitchHunters - A citizen science project for the improvement of gravitational wave detectors

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Gravitational-wave detectors are very sophisticated instruments devoted to the formidable task of measuring spacetime deformations as small as a thousandth the size of the atomic nucleus, such as those produced by astrophysical phenomena like the coalescence of compact binary systems. GWitchHunters is a new citizen science initiative developed within the REINFORCE project (funded under the H2020 "Science With And For Society" program), aimed at promoting the study of the noise of gravitational-wave detectors and the improvement of their sensitivity. To achieve this goal, gravitational-wave data is presented to the citizens in the form of images and sounds, on which citizens are asked to perform quick-look analysis, such as identifying relations and patterns among them. This constitutes an important input to the detector characterization activity carried out by the researchers. To make the work done by the participants even more enjoyable, we have made use of the Zooniverse web platform and mobile app, where citizens can get entertained while learning and actively contributing to real science. We will report on the status of the project as well as on its impact on the study and characterization of noise in Advanced gravitational-wave detectors.

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1. Introduction

The gravitational-wave (GW) observations by the Advanced LIGO [1] and Advanced Virgo [2] detectors have provided a wealth of new insights into fundamental physics research and astrophysics [3]. These include new strong-field tests of general relativity [4] and of the neutron-star-matter equation of state [5], and the discovery of a new population of black holes [6] and compact objects not predicted by standard stellar evolution channels [7, 8]. These achievements are delivered to the general public mainly through scientific outreach activities and press coverage. While being effective in temporarily drawing interest to science, this approach does not provide opportunities for a collective active participation in the pursuit of new scientific knowledge. Going beyond outreach, *citizen science* has the great potential to bridge the gap between cutting-edge research in physics and society, and the ability to support citizens to become critical consumers of and contributors to scientific knowledge.

REINFORCE (REsearch INfrastructures FOR Citizens in Europe)[1] is a "Science with and for society" (SwafS) project, funded by the EU–H2020 research programme, with the aim to engage and support citizens to cooperate with researchers at world-leading large research infrastructures, such as CERN or the European Gravitational Observatory – EGO, and actively contribute in the development of new knowledge for the needs of science and society. This mission has been accomplished with the implementation of a set of four *demonstrators*, citizens-powered research infrastructures on the Zooniverse web platform,[2] where to explore, support, and contribute to the research carried out by the researchers in the fields of Gravitational-Wave Astronomy (Virgo detector), High-Energy Physics (ATLAS experiment at CERN), Neutrino Physics and Astronomy (KM3NeT experiment) and Cosmic Muon Tomography. All of these demonstrators have participated in the 2022, International Conference on High-Energy Physics (ICHEP 2022). In this contribution to the conference proceedings, we will present the *GWitchHunters* demonstrator, for the improvement of the currently operating GW detectors, Advanced LIGO and Advanced Virgo, through the characterization of their noise sources. We will outline the framework of this project and present the preliminary results achieved from the cooperation of researchers and citizens.

2. The GWitchHunters demonstrator

GWitchHunters,[3] form the blending of the words *GW–glitch–hunters* (pronounced: [gwɪtʃ hʌntərz]), aims at promoting the research carried out at GW detectors, providing public access to the data recorded by these instruments and directly involving the citizens, alongside researchers, in the improvement of the sensitivity of the currently operating detectors for the experimental study of the Universe and the fundamental laws of Nature. In particular, the demonstrator focusses on *transient signals*, like those expected from the coalescence of compact binary stars, such as the celebrated first detection event GW150914 [9], or other short excesses of energy of environmental or instrumental origin, colloquially referred to as *glitches* [10]. These glitches constitute a source of noise as they can mimic GW signals or mask their presence, hence reducing the sensitivity of

[1] REINFORCE, www.reinforceeu.eu

[2] Zooniverse.org.

[3] GWitchHunters, www.zooniverse.org/projects/reinforce/gwitchhunters.

our detectors to the astrophysical signals. For this reason, it is of paramount importance to develop strategies to identify the glitches, distinguish them from the astrophysical signals, and track their origins in order to mitigate the noise sources that are more likely to produce them. This is the task citizens are asked to accomplish in GWitchHunters.

The first step has been to find means of communication with which to present the GW data, typically recorded and analyzed in the form of time series, to the general public in a profitable and enjoyable way, without requiring any scientific expertise or prior data analysis experience. GWitchHunters does that by making use of spectrogram images, which are heat maps showing the evolution of the signal energy with time and frequency. Moreover, in order to make concepts like energy and frequency more accessible, REINFORCE has developed new sonorization strategies to convert spectrograms into sounds. This is achieved in GwitchHunters by associating every frequency interval of these spectrograms to the corresponding note of the C major scale of Occidental music, which corresponds to the white keys of a piano keyboard. Then, the energy in each band is associated with the intensity one plays the corresponding note.

From these images and sounds, one can recognize the peculiar shapes and tones associated with the coalescence of compact binary stars and those from noise glitches, which scientists seek to remove. This is one of the tasks that the participants in this project are asked to accomplish.

Besides the data channel that records the GW strain, our detectors constantly monitor the status of their instruments and environment with dedicated data acquisition channels. If we observe the simultaneous presence of a glitch in the main channel and in any of the latter, then this provides evidence for a terrestrial (*i.e.*, instrumental or environmental) origin for that, and also provides researchers information on where in the detector this noise has originated from. This is very important for the identification of the various noise sources and, by removing them, the improvement of the detector sensitivities. This is another task proposed to the citizens in GWitchHunters.

This project is available via the Zooniverse web platform and mobile app, which include user-friendly interfaces for data visualization and performing the described tasks, as well as discussion boards about the science of GW detectors and forums where people can directly interact with the researchers working at the detectors.

3. Project impact and conclusions

In one year from the launch of the project, dated 16 November 2021, about 6,000 volunteers have contributed to it by scoring 600,000 glitch classifications. These have provided a valuable help to the researchers working on the improvement of GW detectors. The data from these classifications can also be used for developing new strategies to identify noise transients and determine their likely causes. In particular, this data has been used to train algorithms based on artificial neural networks to automatically classify glitches [11, 12]; further developments are ongoing to extend the algorithms also to the identification of the correlations with the auxiliary channels, and from that the most likely causes. Beyond that, the contribution of the citizens still remains the most valuable asset in support of the researchers; when new datasets are available from observing runs and for the unique capability people have to spot subtle details and correlations in images and sounds, even from a very small set of examples. The discussion boards on the GWithHunters platform have already provided Virgo researchers with brilliant contributions and hints in this sense.

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References

[1] LIGO Scientific collaboration, *Advanced LIGO*, *Class. Quant. Grav.* **32** (2015) 074001 [1411.4547].

[2] VIRGO collaboration, *Advanced Virgo: a second-generation interferometric gravitational wave detector*, *Class. Quant. Grav.* **32** (2015) 024001 [1408.3978].

[3] B.S. Sathyaprakash et al., *Extreme Gravity and Fundamental Physics*, *arXiv e-prints* (2019) [1903.09221].

[4] LIGO Scientific, VIRGO, KAGRA collaboration, *Tests of General Relativity with GWTC-3*, *arXiv e-prints* (2021) [2112.06861].

[5] E. Annala, T. Gorda, A. Kurkela and A. Vuorinen, *Gravitational-wave constraints on the neutron-star-matter Equation of State*, *Phys. Rev. Lett.* **120** (2018) 172703 [1711.02644].

[6] LIGO Scientific, VIRGO, KAGRA collaboration, *The population of merging compact binaries inferred using gravitational waves through GWTC-3*, *arXiv e-prints* (2021) [2111.03634].

[7] LIGO Scientific, Virgo collaboration, *Properties and Astrophysical Implications of the 150 $M_\odot$ Binary Black Hole Merger GW190521*, *Astrophys. J. Lett.* **900** (2020) L13 [2009.01190].

[8] LIGO Scientific, Virgo collaboration, *GW190814: Gravitational Waves from the Coalescence of a 23 Solar Mass Black Hole with a 2.6 Solar Mass Compact Object*, *Astrophys. J. Lett.* **896** (2020) L44 [2006.12611].

[9] LIGO Scientific, Virgo collaboration, *Observation of Gravitational Waves from a Binary Black Hole Merger*, *Phys. Rev. Lett.* **116** (2016) 061102 [1602.03837].

[10] L.K. Nuttall, *Characterizing transient noise in the LIGO detectors*, *Phil. Trans. Roy. Soc. Lond. A* **376** (2018) 20170286 [1804.07592].

[11] M. Zevin et al., *Gravity Spy: Integrating Advanced LIGO Detector Characterization, Machine Learning, and Citizen Science*, *Class. Quant. Grav.* **34** (2017) 064003 [1611.04596].

[12] M. Razzano and E. Cuoco, *Image-based deep learning for classification of noise transients in gravitational wave detectors*, *Class. Quant. Grav.* **35** (2018) 095016 [1803.09933].