VIGILant: an automatic classification pipeline for glitches in the Virgo detector

Tiago Fernandes, Alejandro Torres-Forné, José A. Font, António Onofre, Francesco Di Renzo

14th Iberian Gravitational Waves Meeting - June 23th 2025

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Introduction

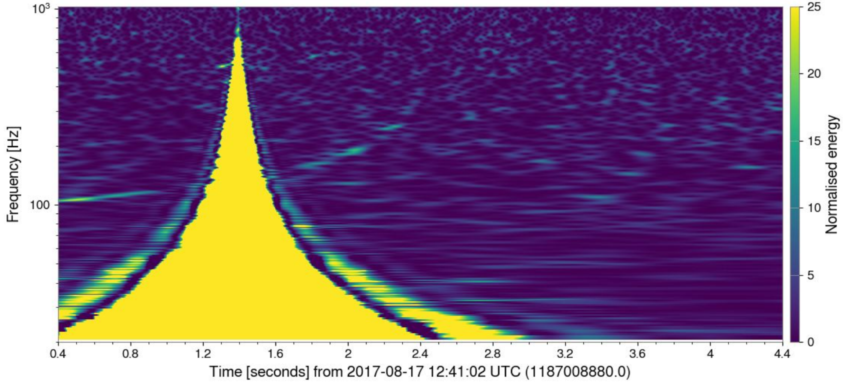
- LVK gravitational-wave detectors are dominated by noise, with rare and weak GW signals.

- **Glitches** are short-duration bursts of excess power with instrumental or environmental origin.

- Glitches **negatively impact GW parameter estimation** and can also **generate false alerts**.

- O(1) glitches per minute → **high chance of coincidence with a GW**.

GW170817 - Livingston strain



GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral

B. P. Abbott[1], R. Abbott[1], T. D. Abbott[2], F. Acernese[3,4], K. Ackley[5,6], C. Adams[7], T. Adams[8], P. Addesso[9], and R. X. Adhikari[1] *et al.*
(LIGO Scientific Collaboration and Virgo Collaboration)

Show more

Phys. Rev. Lett. **119**, 161101 – **Published 16 October, 2017**
DOI: https://doi.org/10.1103/PhysRevLett.119.161101

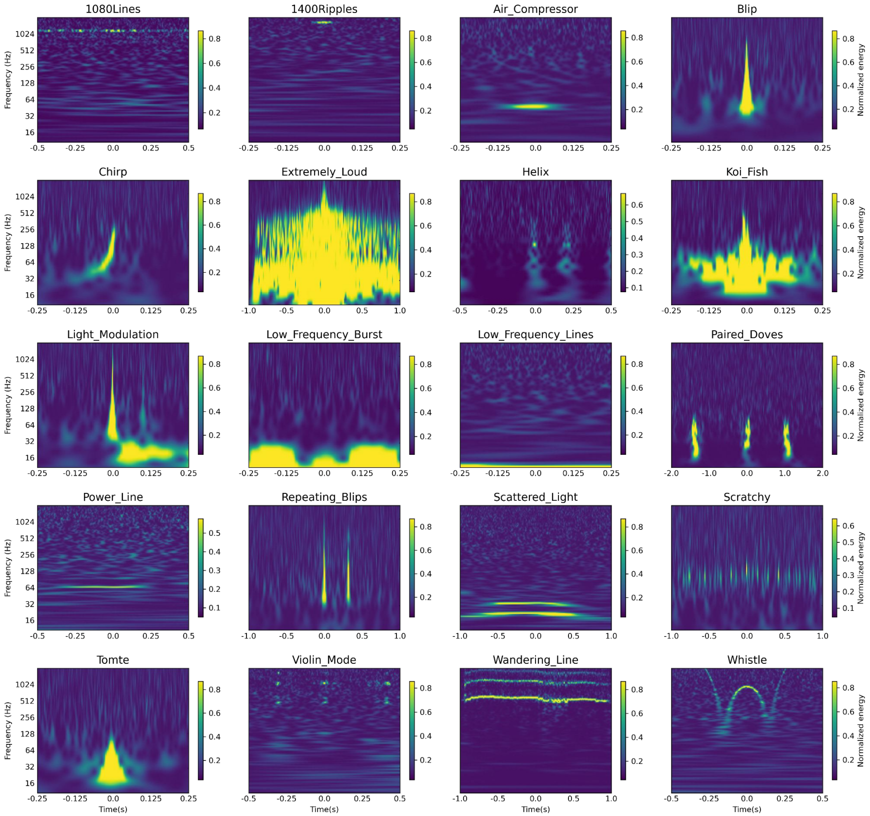
arXiv:1710.05832

Introduction

- Glitches can be categorized by their morphology into **glitch families**.

- Glitches sharing the same morphology should have similar origin. Thus, identifying the class of a given glitch can be useful to find its origin.

- How can this classification be done?



Introduction

- **Omicron** detects glitches and provides their basic characteristics. However, it is not designed to classify glitches.

- **GravitySpy** and **GWitchHunters** have used volunteer classifications to label glitches triggered by Omicron. These labelled glitches are then used to train ML glitch classification algorithms.

- However, at the start of O4, **we did not have an active glitch classification project focused on labelling Virgo glitch data**.

Contents lists available at ScienceDirect
SoftwareX
journal homepage: www.elsevier.com/locate/softx
ELSEVIER

Original software publication
Omicron: A tool to characterize transient noise in gravitational-wave detectors
Florent Robinet [a,*], Nicolas Arnaud [a], Nicolas Leroy [a], Andrew Lundgren [b], Duncan Macleod [c], Jessica McIver [d]

arXiv:2007.11374

Classical and Quantum Gravity

PAPER
Gravity Spy: integrating advanced LIGO detector characterization, machine learning, and citizen science
M Zevin[1], S Coughlin[1], S Bahaadini[2], E Besler[2], N Rohani[2], S Allen[3], M Cabero[4], K Crowston[5], A K Katsaggelos[2], S L Larson[1,3] Show full author list
Published 28 February 2017 • © 2017 IOP Publishing Ltd
Classical and Quantum Gravity, Volume 34, Number 6
Citation M Zevin *et al* 2017 *Class. Quantum Grav.* **34** 064003
DOI 10.1088/1361-6382/aa5cea

arXiv:1611.04596

ELSEVIER
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment
Volume 1048, March 2023, 167959

GWitchHunters: Machine learning and citizen science to improve the performance of gravitational wave detector
Massimiliano Razzano [a b 1], Francesco Di Renzo [a b], Francesco Fidecaro [a b], Gary Hemming [c], Stavros Katsanevas [c]

arXiv:2301.05112

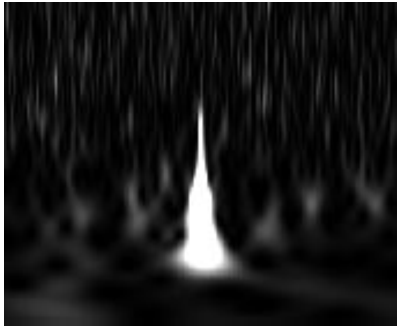
Project overview

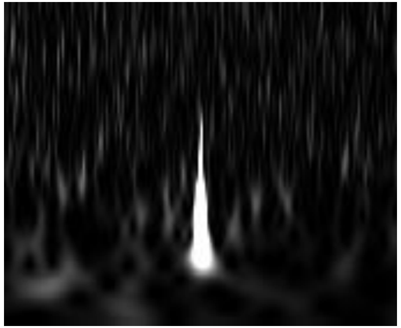
VIGILant (**Vi**rgo **G**litch **I**dentification and **L**earning) aims to develop and deploy an **automatic classification pipeline for Virgo glitches**.

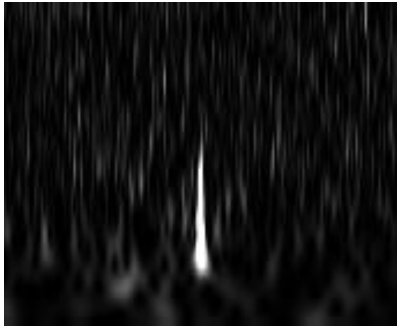
1. Produce a labelled Virgo glitch spectrogram dataset;
2. Create a supervised ML classifier;
3. Create visual output for the classifier;
4. Deploy automatic pipeline in the Virgo cluster;
5. Investigate possible improvements in dataset and model;
6. Identify anomalies in the glitch classification;
7. Incorporate the new classes and the possible morphology changes in the supervised classification algorithm.

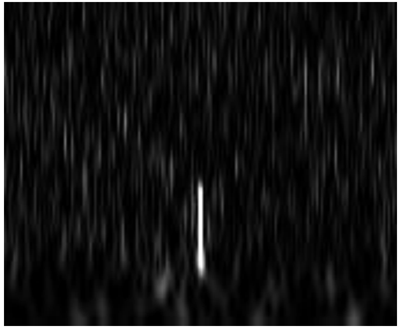
Dataset generation

- Virgo O3a data
- GPS times obtained from Omicron, labels from the GravitySpy ML model.
- For each glitch, four spectrograms are generated.


0.5 seconds view

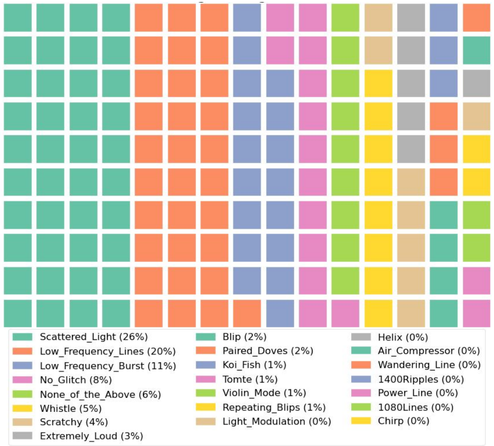

1.0 seconds view


2.0 seconds view


4.0 seconds view

Dataset generation

O3a: 80398 glitches



select glitches with label confidence = 1.0

11323 glitches

remove glitches from classes with less than 100 samples

80% training
20% validation

```
Training dataset
----------------------------------
Scattered_Light     :  6389 samples
Low_Frequency_Lines :  1240 samples
Low_Frequency_Burst :   981 samples
Extremely_Loud      :   975 samples
Blip                :   874 samples
Koi_Fish            :   188 samples
None_of_the_Above   :   168 samples
Whistle             :   139 samples
Repeating_Blips     :   133 samples
----------------------------------
Total (9 classes)     11087 samples
```

ML model training

- ResNet18 architecture


arXiv > cs > arXiv:1512.03385

Computer Science > Computer Vision and Pattern Recognition

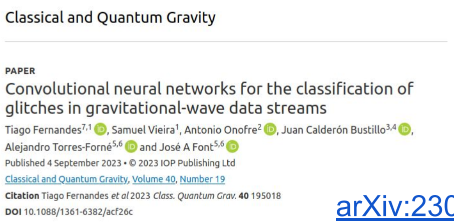
[Submitted on 10 Dec 2015]

Deep Residual Learning for Image Recognition

Kaiming He, Xiangyu Zhang, Shaoqing Ren, Jian Sun

arXiv:1512.03385

- Data is input in an “encoded” view


Classical and Quantum Gravity

PAPER

Convolutional neural networks for the classification of glitches in gravitational-wave data streams

Tiago Fernandes[7,1], Samuel Vieira[1], Antonio Onofre[2], Juan Calderón Bustillo[3,4], Alejandro Torres-Forné[5,6] and José A Font[5,6]

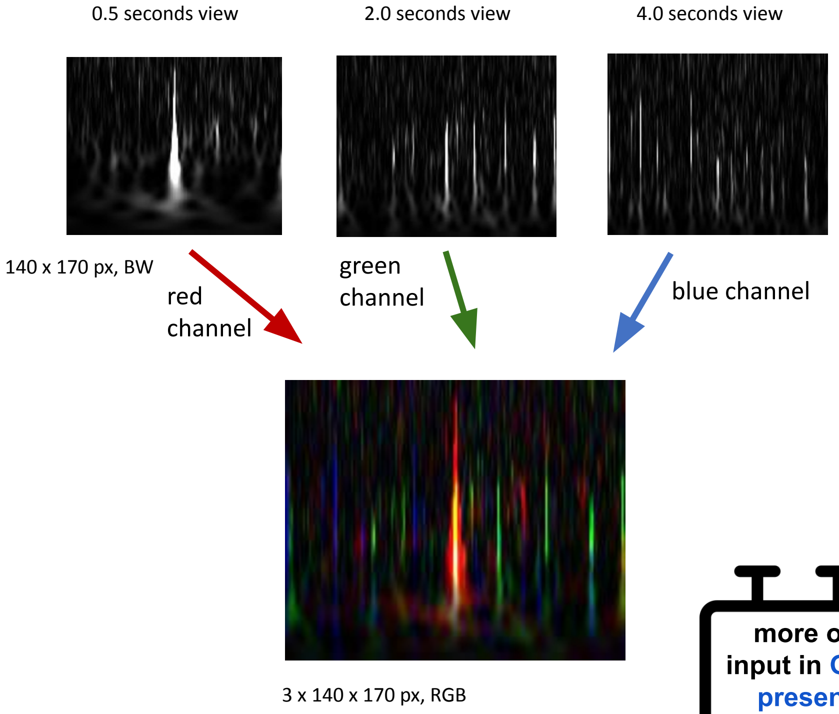
Published 4 September 2023 • © 2023 IOP Publishing Ltd

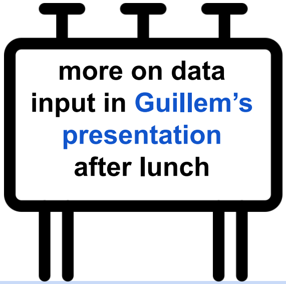
Classical and Quantum Gravity, Volume 40, Number 19

Citation Tiago Fernandes *et al* 2023 *Class. Quantum Grav.* **40** 195018

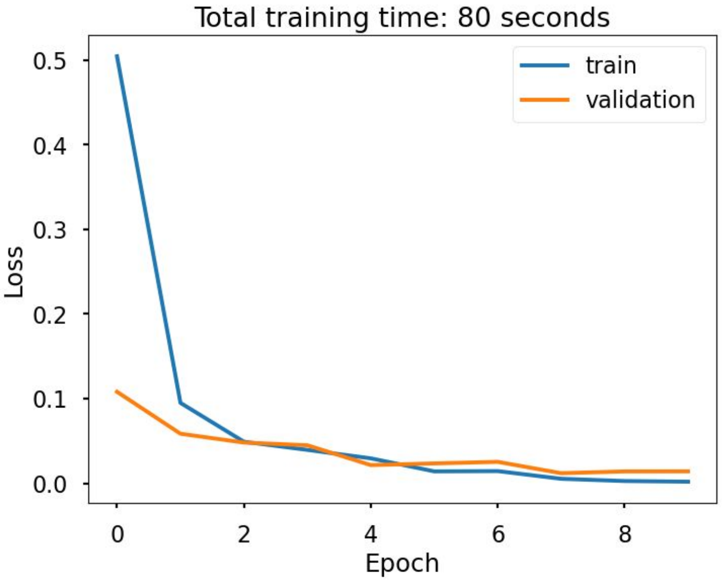
DOI 10.1088/1361-6382/acf26c

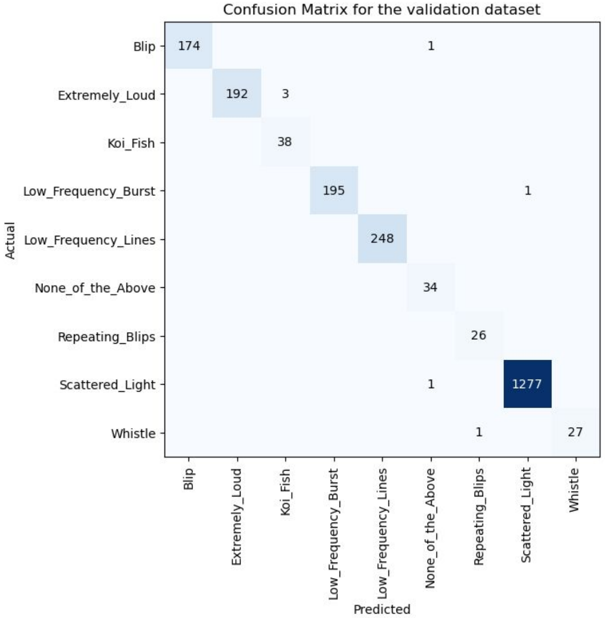
arXiv:2303.13917





ML model training

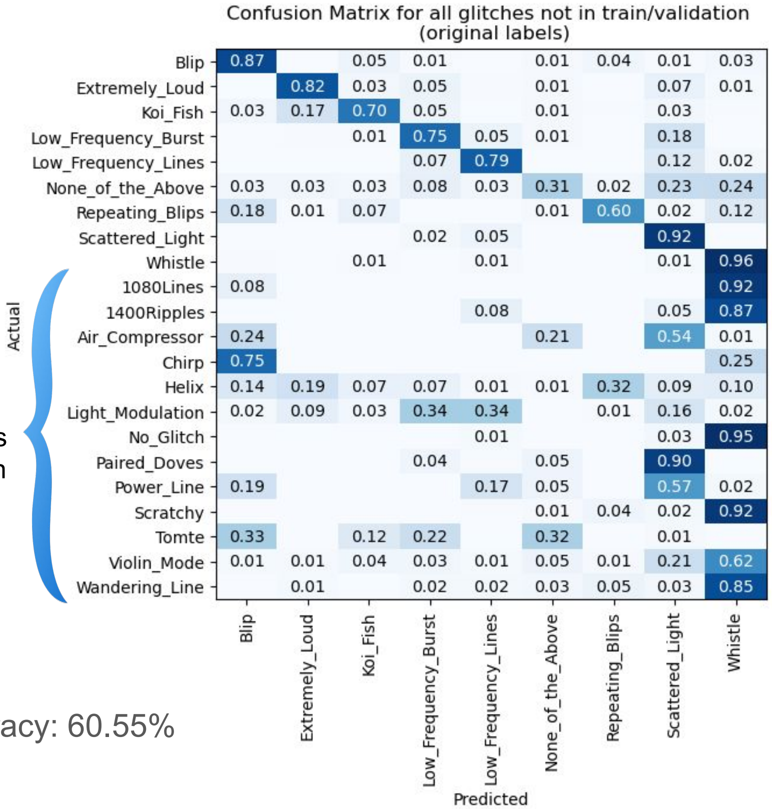




Accuracy: 99.7%

Accurate ML model trained in less than 2 minutes.

ML model generalization



classes unseen by the model

Accuracy: 60.55%

- Issues:
  - GravitySPy ML labels are noisy
  - None_of_the_Aboves and unseen classes are hard to handle with a supervised model

- Possible solutions:
  - improve labels
  - find outliers based on model confidence
  - …

Putting the pipeline into production

(time, freq., SNR)

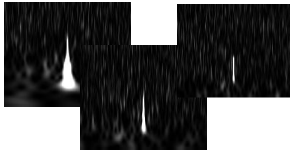
Omicron glitch parameters

glitch dashboard

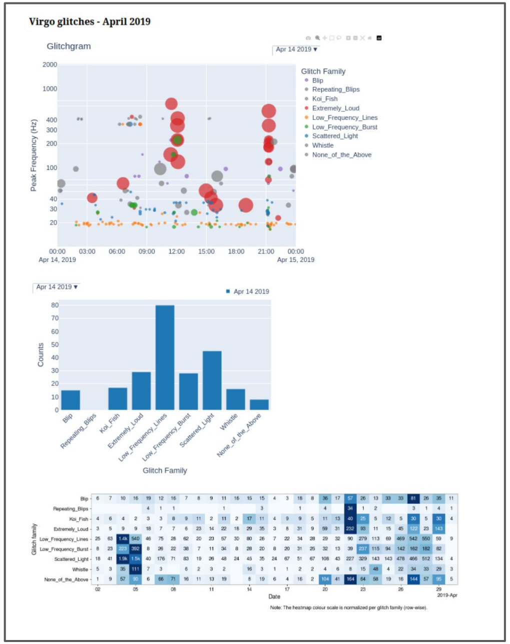
new Omicron triggers

glitch families

Glitch spectrograms



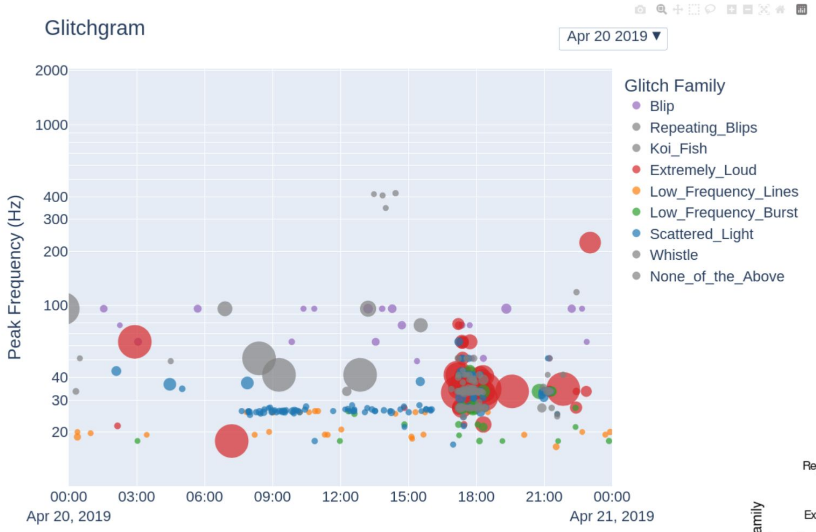
Trained ML model

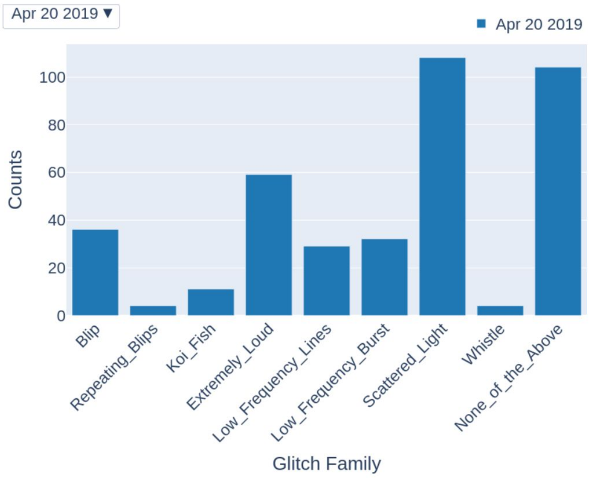


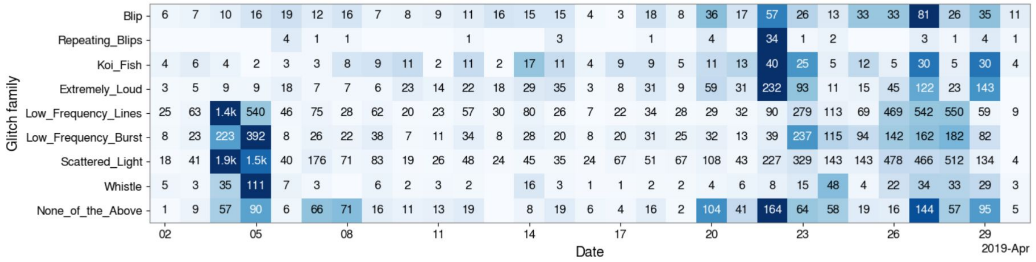
📅 cronjob running everyday at 2 AM on a Virgo machine;
3 seconds / glitch

Dashboard demo

Virgo glitches - April 2019







Note: The heatmap colour scale is normalized per glitch family (row-wise).

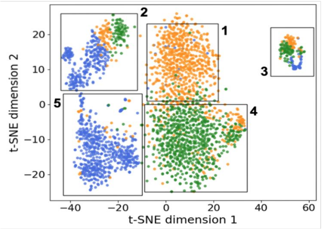
interactive dashboard here

Finding new glitch families

labelled glitches

AutoEncoder training

trained encoder



Laguarta *et al.* (2023)
arXiv:2310.03453

family clusters in latent space

outputs of supervised classification pipeline

uncertain glitches

(None_of_the_Above,
or low confidence predictions)

points in latent space

distance to existing clusters

clustering of points distant to known family clusters

proposal of new glitch classes

Conclusions

- VIGILant is running in Virgo, providing an additional tool for glitch investigations inside the collaboration.

- It is currently the only provider of Virgo glitch classifications.

- Some improvements to adapt the tool for the O4 glitch population are planned.

- In a second phase, a tool to automatically identify new glitch families will be created and integrated in the pipeline.

THANK YOU FOR YOUR ATTENTION!!

Acknowledgements

Tiago Fernandes is supported by FCT - Fundação para a Ciência e Tecnologia, I.P. by project reference 2023.03753.BD and DOI identifier https://doi.org/10.54499/2023.03753.BD.

Work supported by the Spanish Agencia Estatal de Investigación (Grant PID2021-125485NB-C21) funded by MCIN/AEI/10.13039/501100011033 and ERDF A way of making Europe.

This material is based upon work supported by NSF's LIGO Laboratory which is a major facility fully funded by the National Science Foundation, as well as the Science and Technology Facilities Council (STFC) of the United Kingdom, the Max-Planck-Society (MPS), and the State of Niedersachsen/Germany for support of the construction of Advanced LIGO and construction and operation of the GEO600 detector. Additional support for Advanced LIGO was provided by the Australian Research Council. Virgo is funded, through the European Gravitational Observatory (EGO), by the French Centre National de Recherche Scientifique (CNRS), the Italian Istituto Nazionale di Fisica Nucleare (INFN) and the Dutch Nikhef, with contributions by institutions from Belgium, Germany, Greece, Hungary, Ireland, Japan, Monaco, Poland, Portugal, Spain. KAGRA is supported by Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Society for the Promotion of Science (JSPS) in Japan; National Research Foundation (NRF) and Ministry of Science and ICT (MSIT) in Korea; Academia Sinica (AS) and National Science and Technology Council (NSTC) in Taiwan.

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