REINFORCE

REsearch INfrastructures FOR Citizens in Europe

GWitchHunters

A new citizen science project to support gravitational wave physics

Swedish Academy Physics Class Visit
Pisa – 16 June 2022

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GWItchHunters team, on behalf of the REINFORCE Consortium

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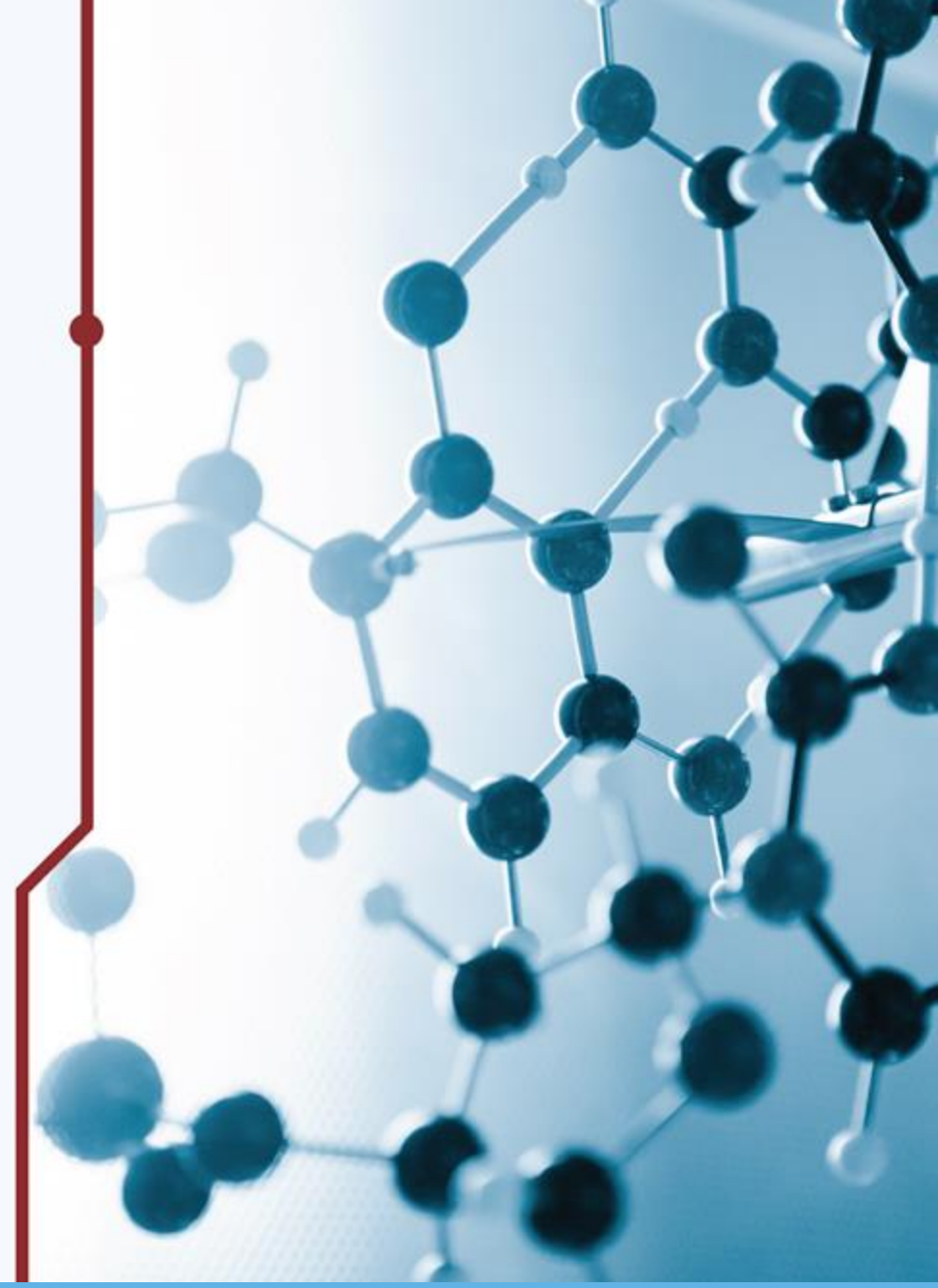


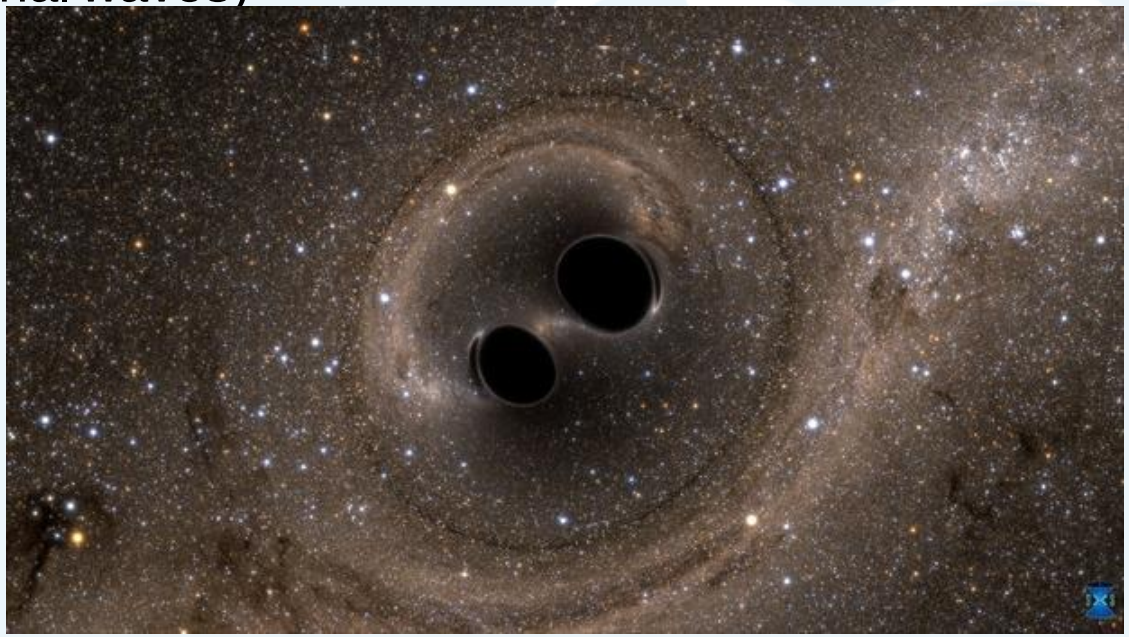
The era of Gravitational Waves

A new window on the Universe

- Study gravitational fields and mass distribution in cosmic sources
- Probing black holes and other “dark” astrophysical sources
- Test general relativity against other theories on gravitation
- Investigate Big Bang cosmology (primordial gravitational waves)

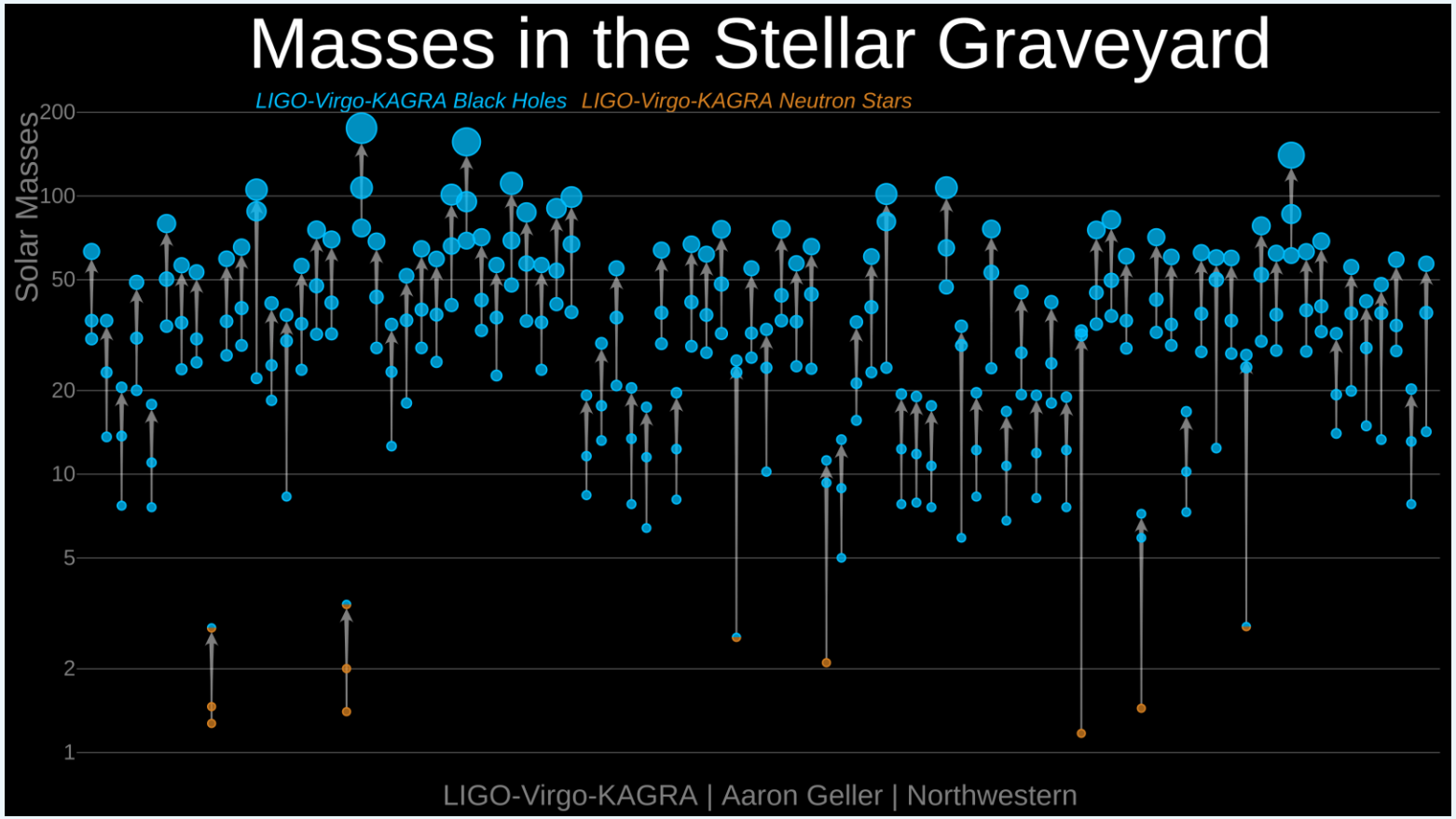
Multimessenger Astrophysics

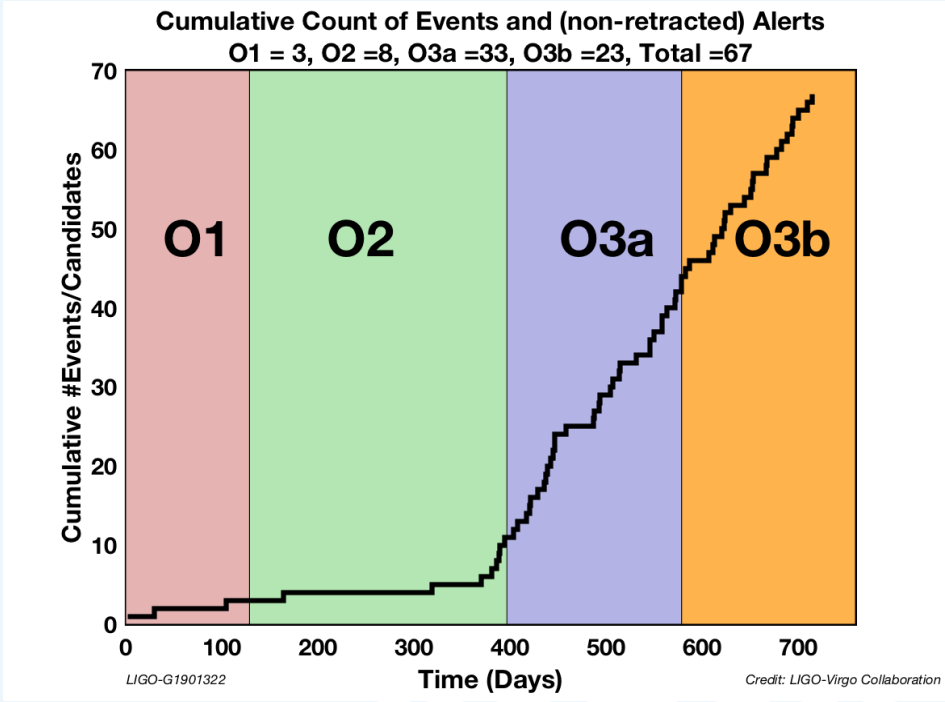
- Traditional astronomy with EM radiation
- Cosmic messengers carrying complementary Information (light, GWs, neutrinos...)



Credits: The SXS

The era of Gravitational Waves





GW Transient Catalogs

GWTC-1: Abbott et al 2019, Physical Review X, 9, 3

GWTC-2: Abbott et al 2021, Physical Review X, 11, 2

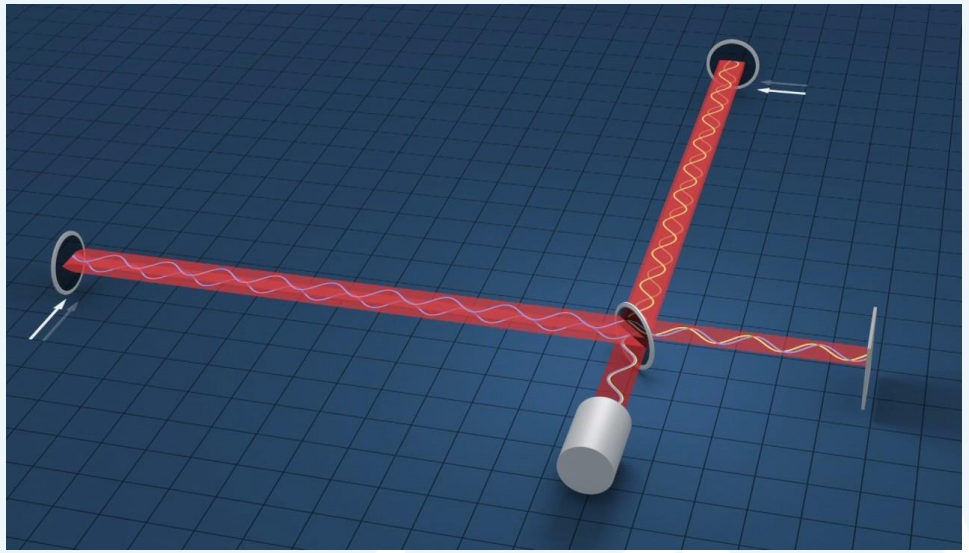
GWTC-2.1: Abbott et al 2021, arXiv: 2108.01045

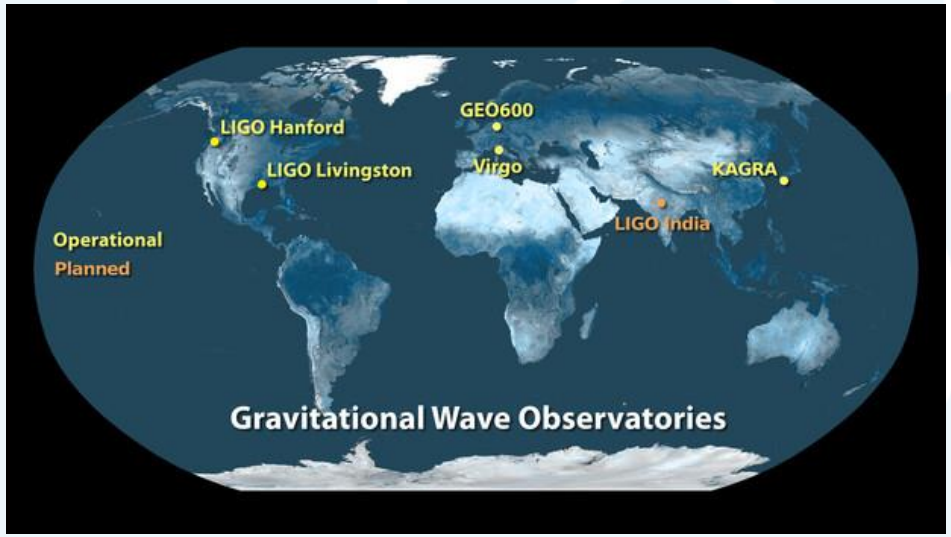
GTWC-3: Abbott et al 2022, arXiv:2111.03606

How to detect gravitational waves

- **Extremely tiny signals**
  - Typical GW sources induce a deformation of 10^{-18} m over a length of ~ few km
  - High background noise!

- **Laser interferometers**
  - Exploiting interference between orthogonal laser beams
  - Typical km-long scale + Fabry-Perot cavities
  - Frequency range ~20-20000 Hz
  - Advanced methods to reduce noise
  - Detectors working as a network

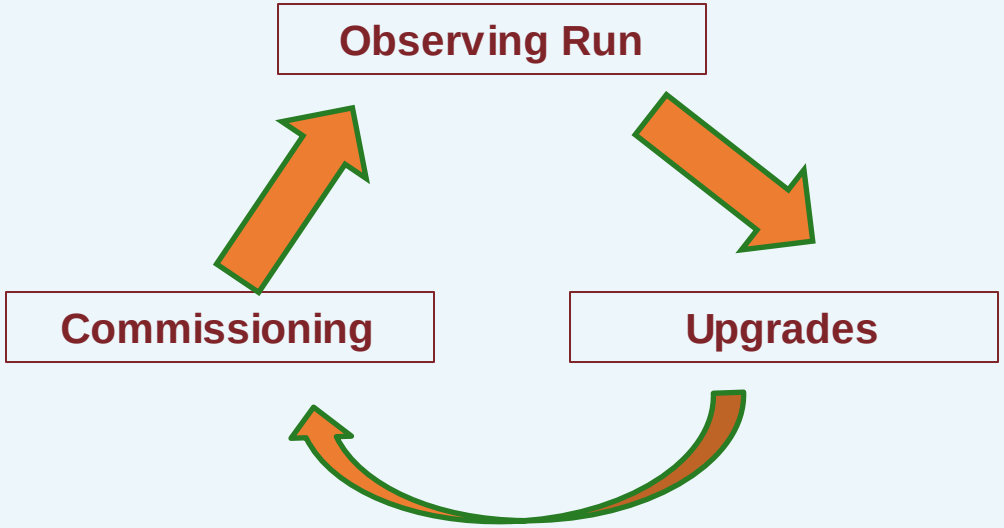




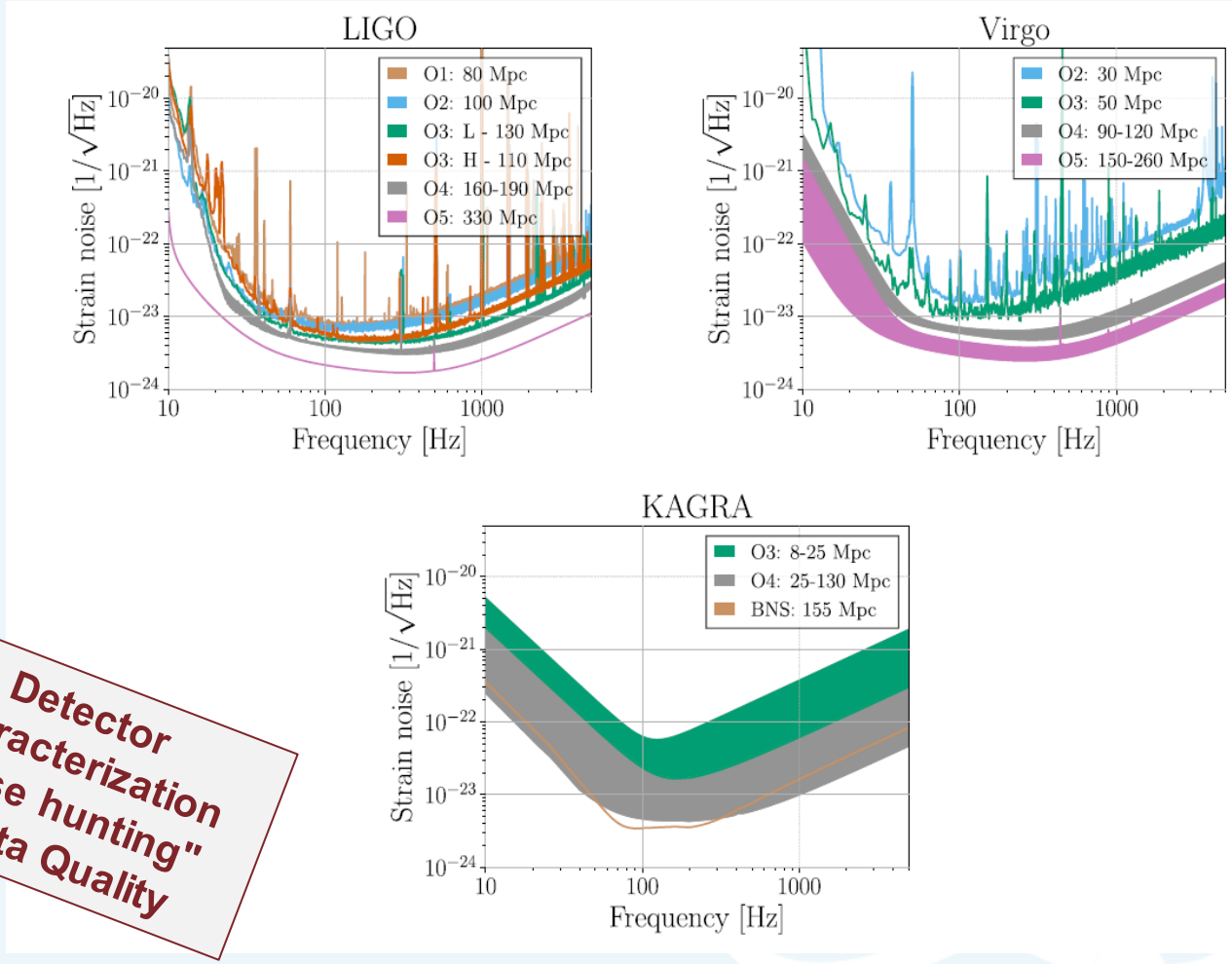
Credits: LIGO/T Pyle; Caltech/MIT/LIGO Lab

Detecting Gravitational Waves

- **Sensitivity varies with frequency: main noise sources**
  - Low frequencies: Newtonian, seismic
  - Mid frequencies: thermal processes
  - High frequencies: quantum noise



Detector Characterization "noise hunting" & Data Quality

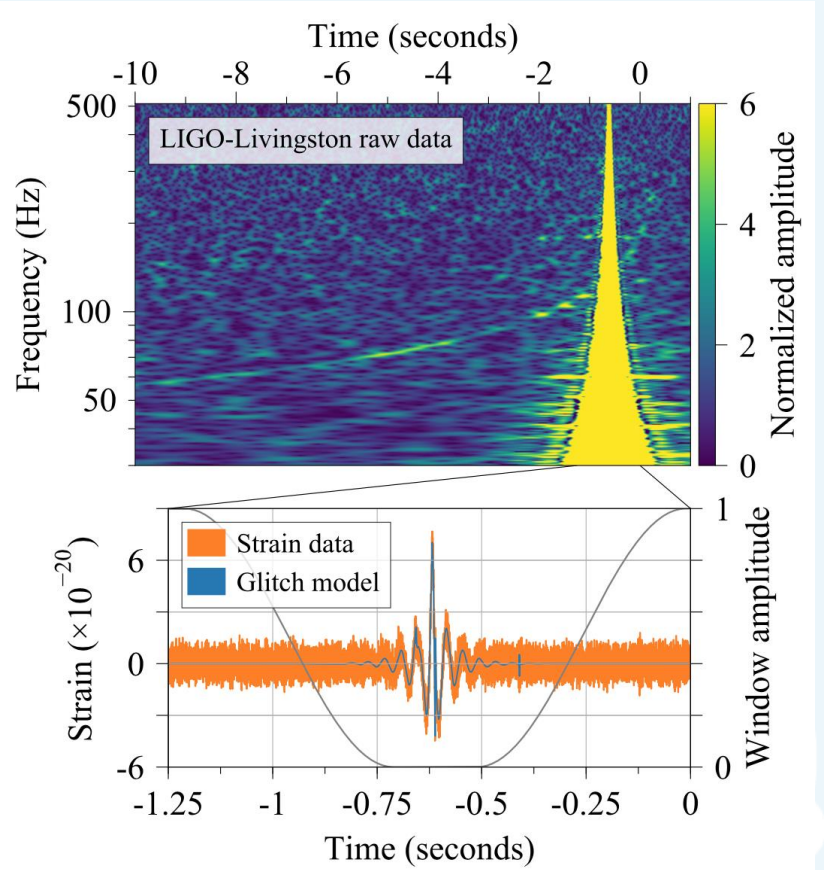


"Observing Scenario" paper
Abbott et al, (LVK collaborations) 2020, LRR, 23, 3

Noise glitches

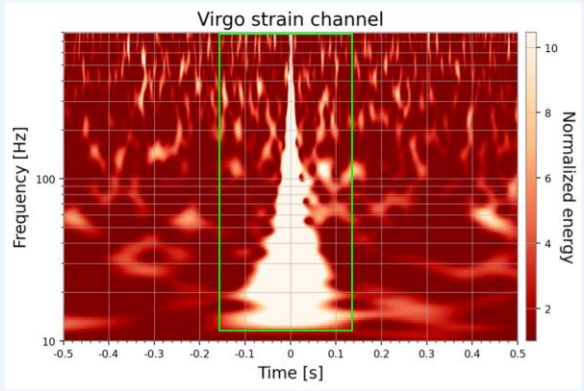
- **Noise is not stationary**
  - Transient noise events can happen
  - Not related to astrophysical source, but local disturbances
  - Different timescales/frequency ranges
  - Affect data quality, stability and GW detection

- **Noise hunting & characterization is critical**
  - Detect and classify glitches to find their origin and remove them
  - Hardware/software origin
  - Data from auxiliary sensors important to understand origin
  - Machine learning offers promising approach (e.g. George&Huerta2017, Razzano&Cuoco 2018)
  - Glitches have complex time-frequency morphologies !

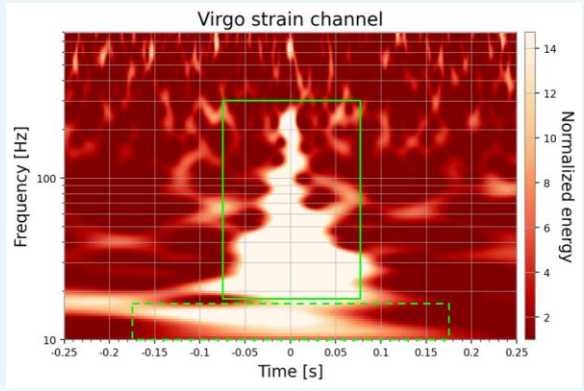


Glitch in LIGO L1 detector during GW170817
Abbott et al 2017

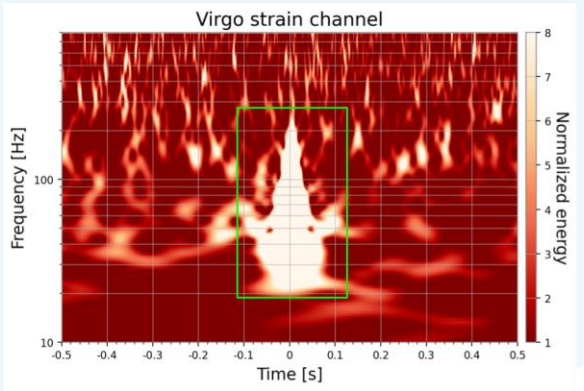
Glitch morphologies



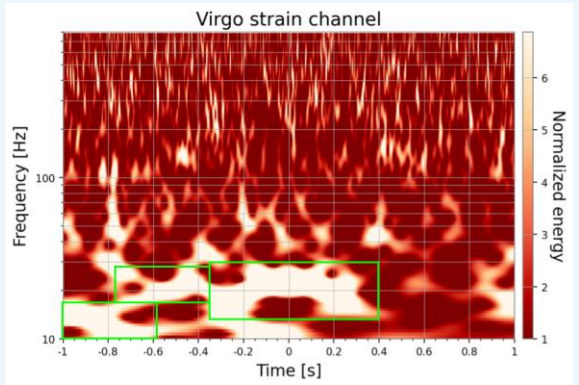
Blip



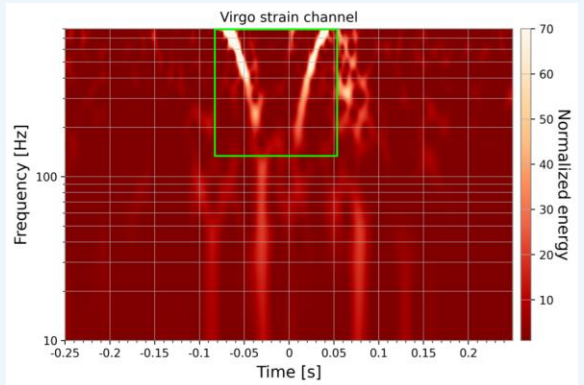
Helix



Koi Fish

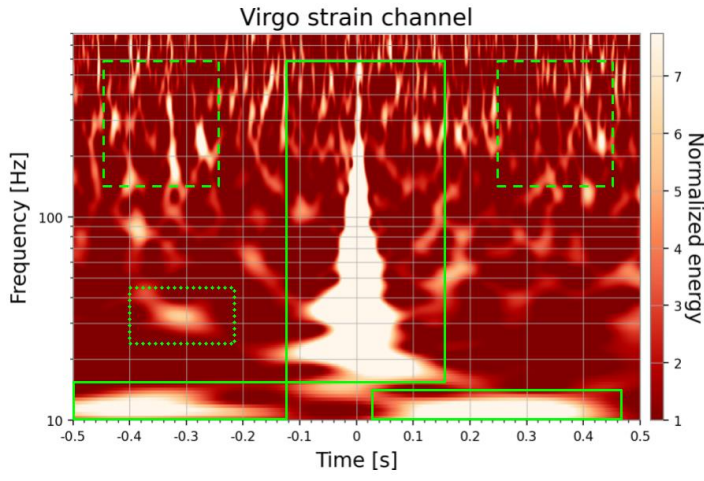


Scattered Light



Whistle

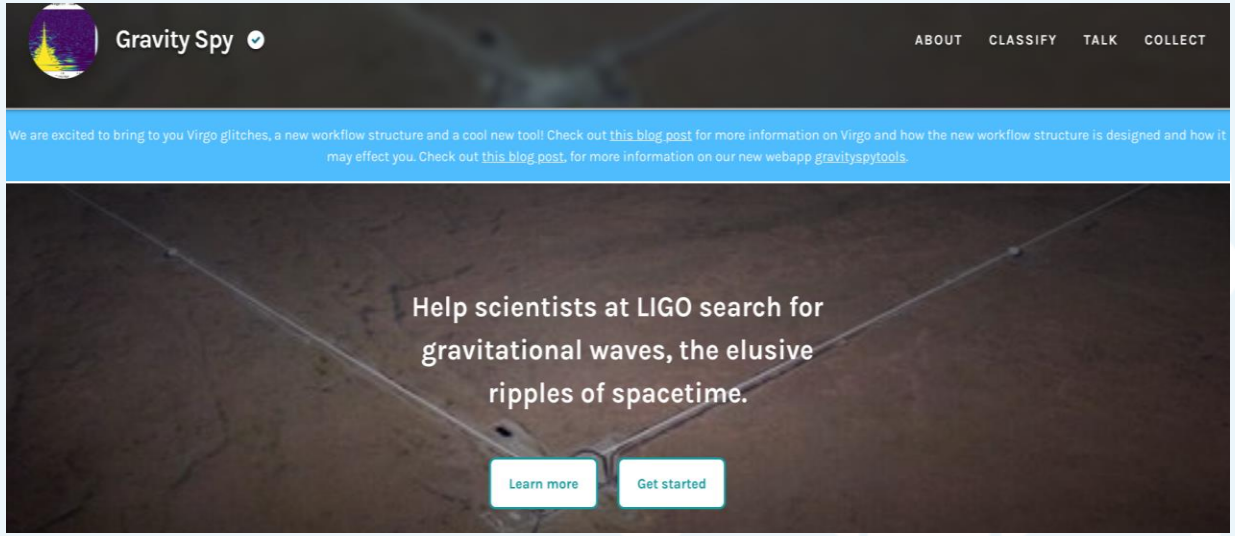
Many Glitches



Glitches and citizen science

- **Machine Learning approach**
  - Promising to classify complex time-frequency patterns of glitches (timeseries/images)
  - Large input required to train machine learning models
  - Not only for detector characterization. Various ML works for GW data analysis
  - Mostly supervised approach

- **Citizen scientists can help**
  - Preparing labeled dataset (à la GalaxyZoo)
  - Time-frequency spectrograms (images)
  - Look at glitches & other noise sources and help characterizing them
  - Unveil novel glitch classes
  - Success story: Gravity Spy on Zooniverse (2016) by LIGO team and NSF



https://www.zooniverse.org/projects/zooniverse/gravity-spy

The REINFORCE Project

- Horizon 2020 SWAFS “Science with and for Society” work program
- Cutting-edge citizen science projects on Frontier Physics Research
- Engage >100k citizens in Large Research Infrastructures in Europe (Virgo, KM3Net, LHC)
- PI S. Katsanevas (EGO)
- Participatory design methodology taking into account the special characteristics of different target groups, their barriers and constraints, their perceptions and biases and their attitudes and knowledge regarding **science**
- Sonification methodologies to increase the senses & inclusion
- Engaging Activities (workshops, schools, etc)

See next talks by W. Diaz-Merced & V. Napolano

REINFORCE and GW

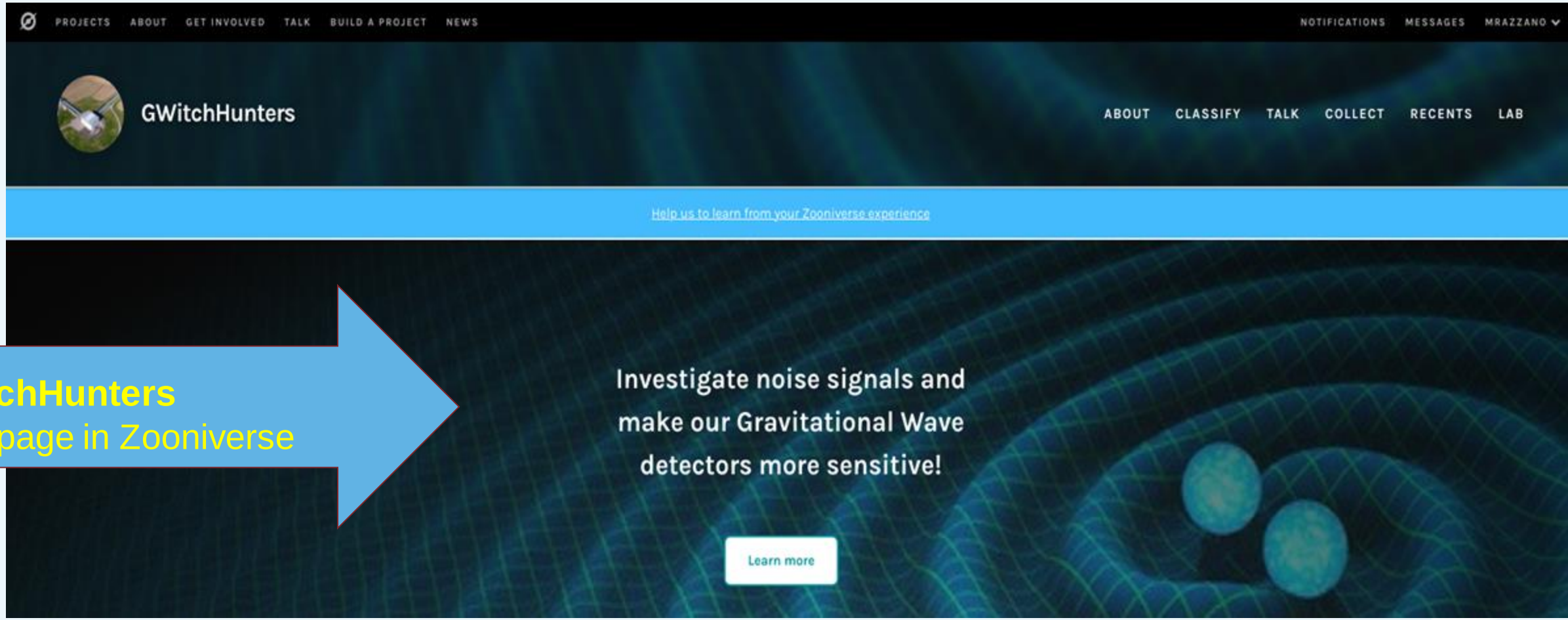
- Citizen science is already supporting gravitational wave science (GravitySpy)
- REINFORCE focus on 4 projects (aka "demonstrators")

https://www.reinforceeu.eu/

Work Package 3
Institutions:
Unipi, EGO,
EA,Conicet,
OU,UXF

- Demonstrators developed on Zooniverse, the leading platform for citizen science
- Our goal: engaging citizens as active participants
- Output used to train machine learning models, but not only that

GW demonstrator development



GWitchHunters
homepage in Zooniverse

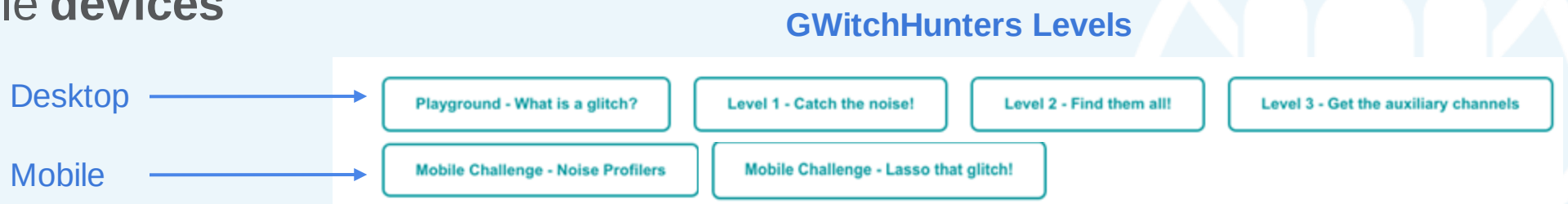
Few words on data

- **Source data**
  - Real data from Advanced Virgo O3 (for the launch, next steps we plan to include LIGO)
  - Main "strain" channel (aka h(t)), also publicly available
  - Auxiliary channels, not public but available thanks to Virgo-EGO-REINFORCE MoA
- **Datasets**
  - Timeseries (+ preprocessing, whitening) to Time-Frequency image maps
  - Two Data Releases so far
    - DR01 (2021, launch) - 2000 glitches from O3a + 8 aux channels
    - DR02 (2022, follow-up) - +4000 glitches from O3b + 8 aux channels

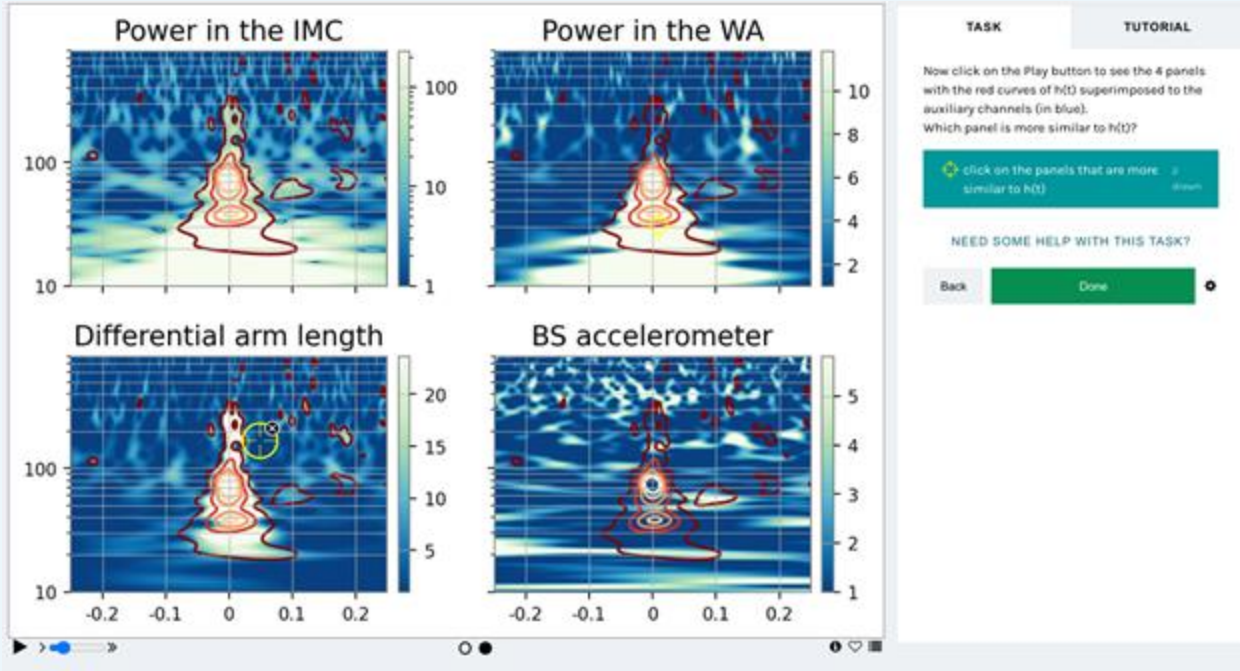
Highlights of GWitchHunters

- Introduce a **new, original** way to power GW research with citizen science
  - *GravitySpy* as a success story
  - Can we expand this approach?

- New frontiers
  - Go beyond classification tasks → **Noise hunting**
  - Not only **glitches**
  - Include signals from sensors in the detector (“**auxiliary channels**”)
  - Run on mobile **devices**



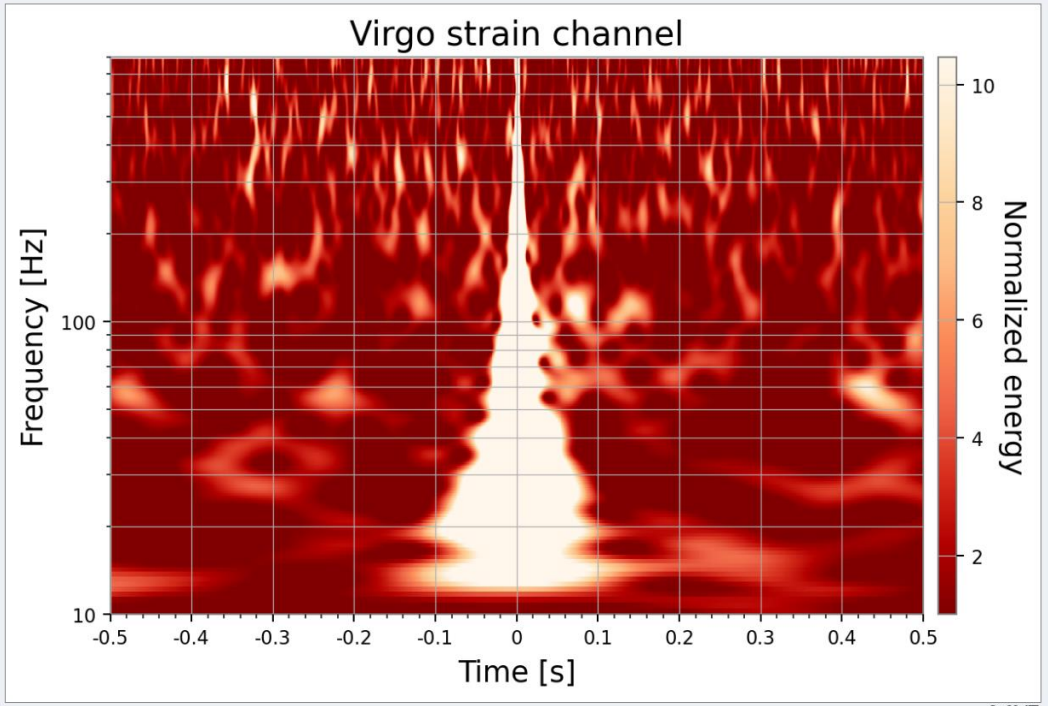
Our Challenges

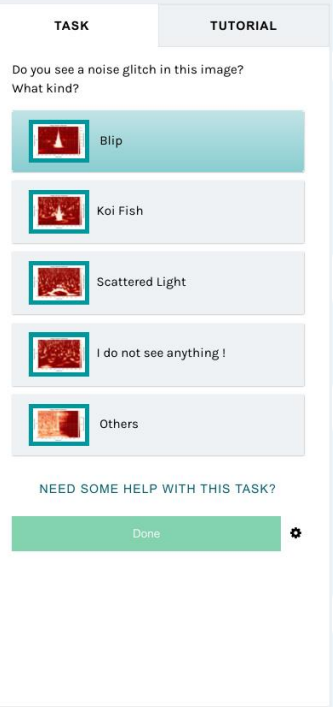


- **Be engaging and innovative**
  - **Attract** GravitySpy fans and more
  - Offer **new challenges** in GW science
- **More data, more fun!**
  - Auxiliary channels offer new insights into **how detectors work**
  - Auxiliary channels are not public. Prepared **ad hoc REINFORCE-EGO MoA**
  - As a result, an **updated & more rich dataset** than first dataset
- **Go beyond glitches**
  - **Flexible workflow**, can accomodate other noise features (lines/slowly-varying noise)

Citizens Tasks - Classification

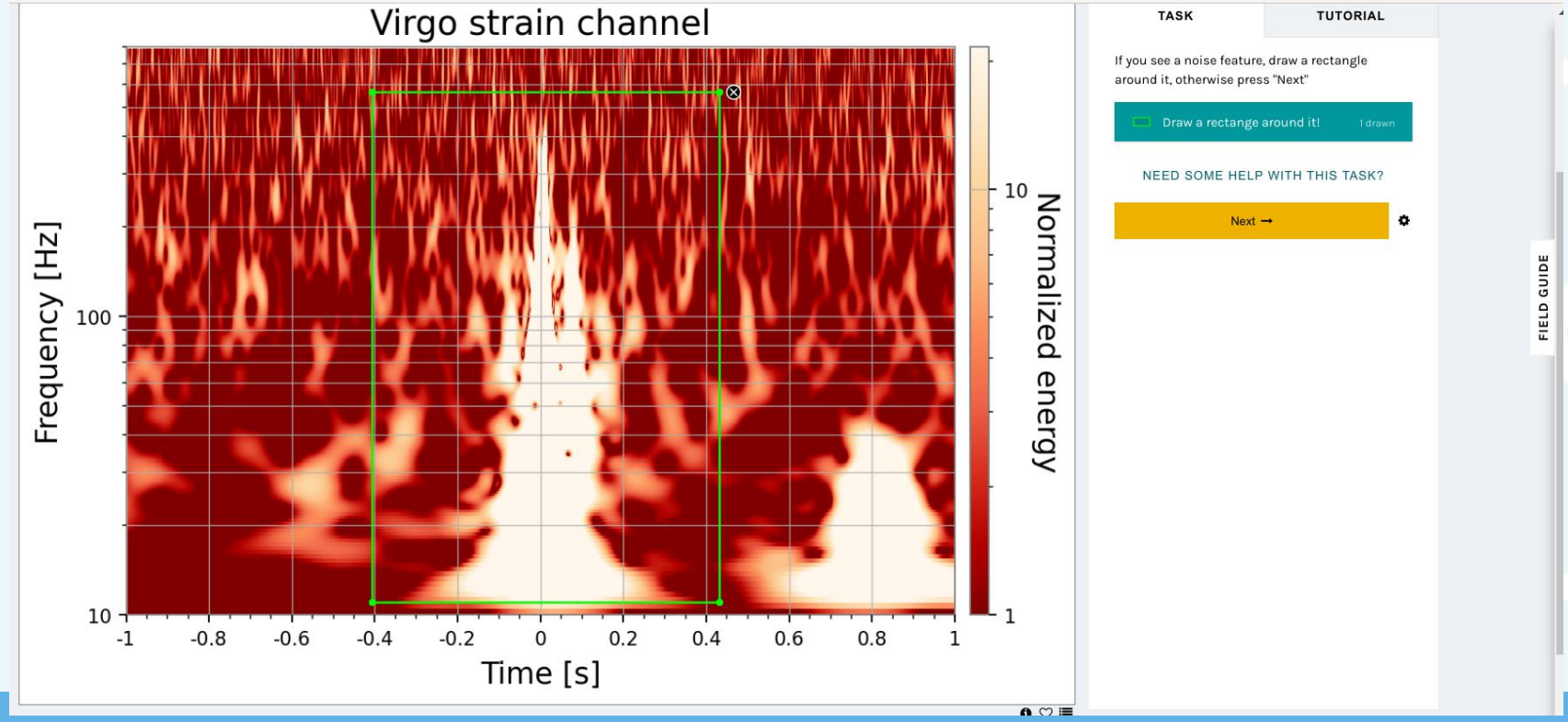
- **Classify noise features**
  - Similar to GravitySpy
  - Data presented as time-frequency spectrograms
  - Meant mainly to introduce participants to the problem and train them





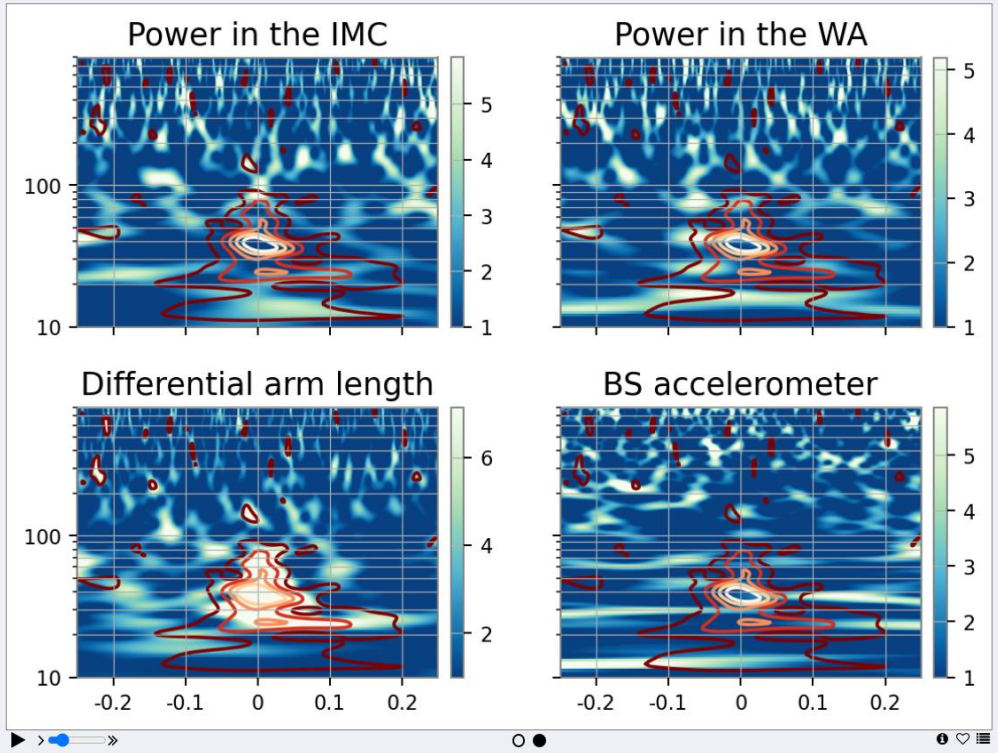
Citizens Tasks - Detection

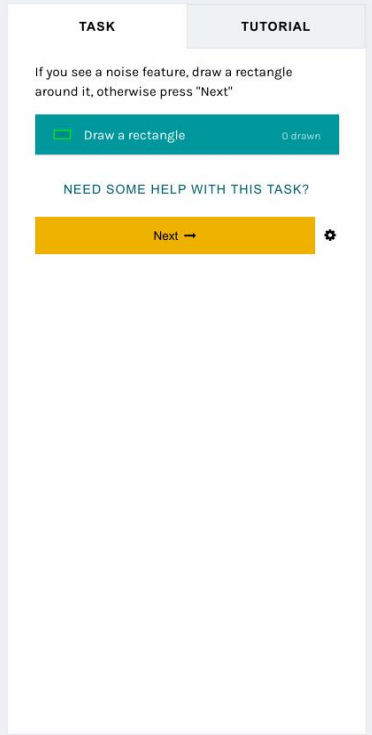
- **Localize the noise**
  - **Draw rectangles around noise features**
  - Can be extended to non-glitch features



Citizens Tasks – Auxiliary Channels

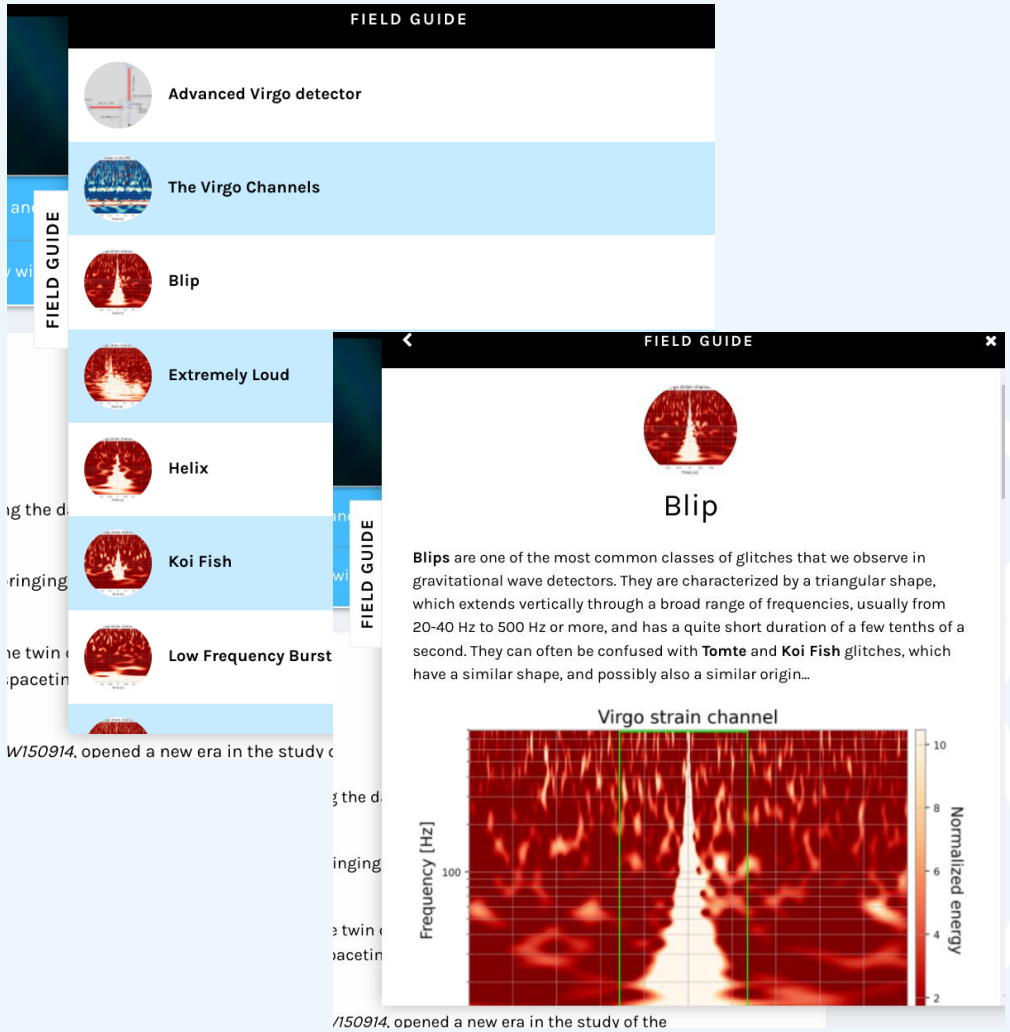
- **Study data from auxiliary sensors**
  - Find similar morphologies between h(t) and aux
  - Initial set of 8 channels, discuss with Virgo experts on others to add





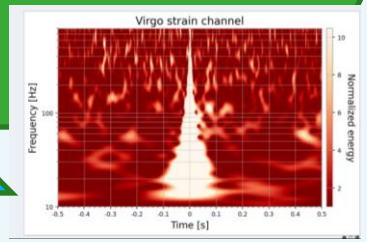
Tutorials and accessibility

- **Introduce the project to non scientists**
  - Detailed tutorials
  - Field Guide on GW detectors, Virgo, glitches
- **Promote engangement**
  - Implement mobile tasks using Zooniverse app
  - Forum to discuss and interact with research team and among citizens
  - Multilanguage support
- **Self-training**
  - Playground level with real-time feedback



GWitchHunters: The big picture

- Glitch triggers
- Noise features



Virgo Glitch Database

GWitchHunters
(labeling and characterization)

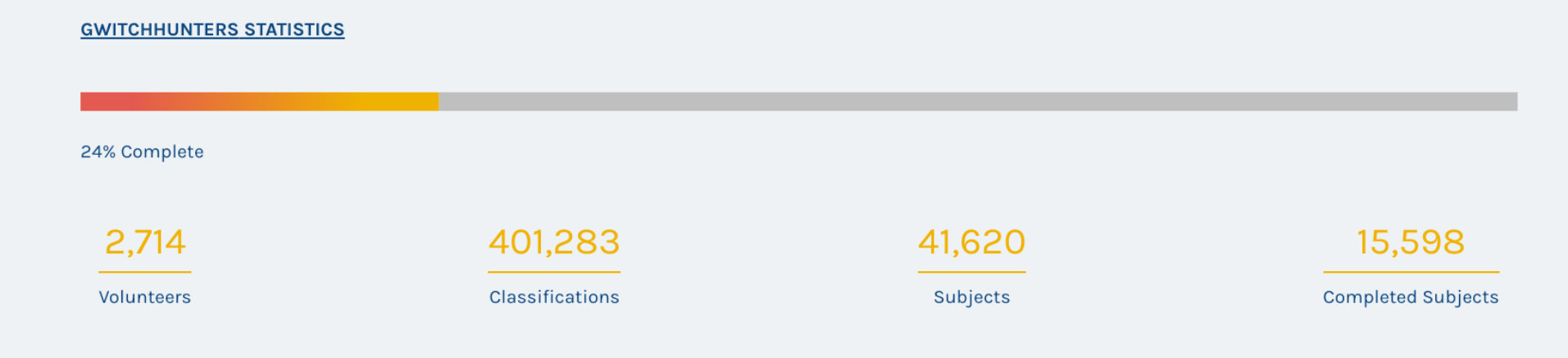
Process & ML training

Classes, aux channels
(i.e., Virgo detchar input)

Where we are

Launched in Nov 2021, very good feedback from the citizens community

Some numbers (Jun 15, 2022):



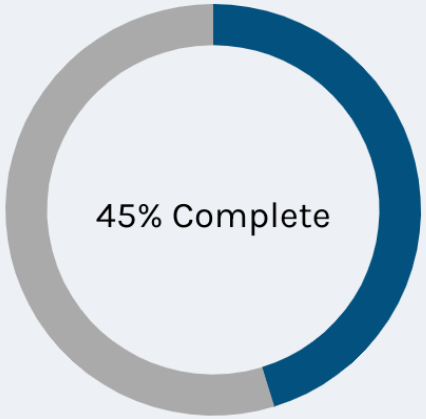
Mobile Challenges done quickly: first data release completed in mid Feb

Status of the tasks

Some tasks are in a very good stage

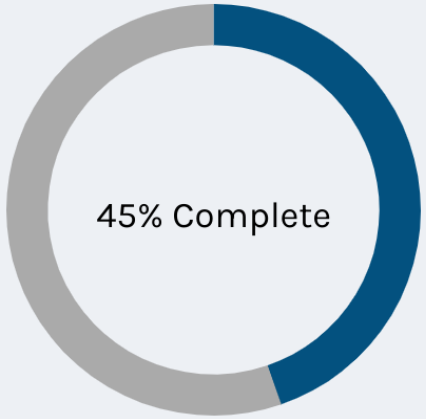
Level 1 - Catch the noise

Retirement limit: 12
Images retired: 1,159 / 4,788
Classifications: 26,024 / 57,456
ETC* 1090 days



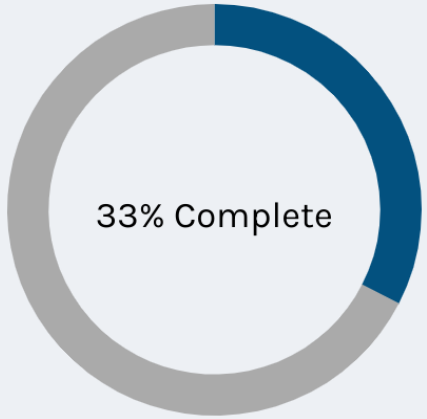
Level 2 - Find them all!

Retirement limit: 12
Images retired: 1,210 / 4,788
Classifications: 25,716 / 57,456
ETC* 128 days



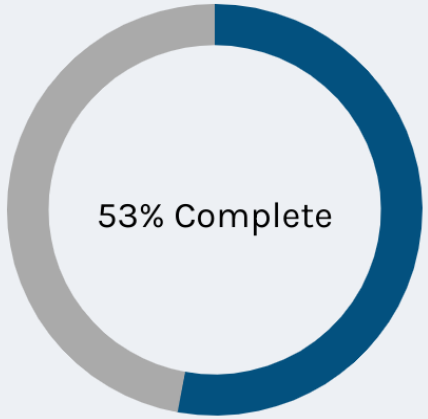
Level 3 - Watch out the sensors!

Retirement limit: 12
Images retired: 1,100 / 6,436
Classifications: 25,143 / 77,232
ETC* 258 days



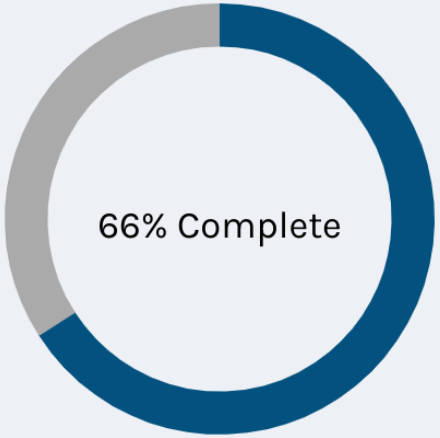
Mobile Challenge - Lasso that glitch!

Retirement limit: 12
Images retired: 1,607 / 5,185
Classifications: 32,921 / 62,220
ETC* 156 days



Mobile Challenge - Noise Profilers

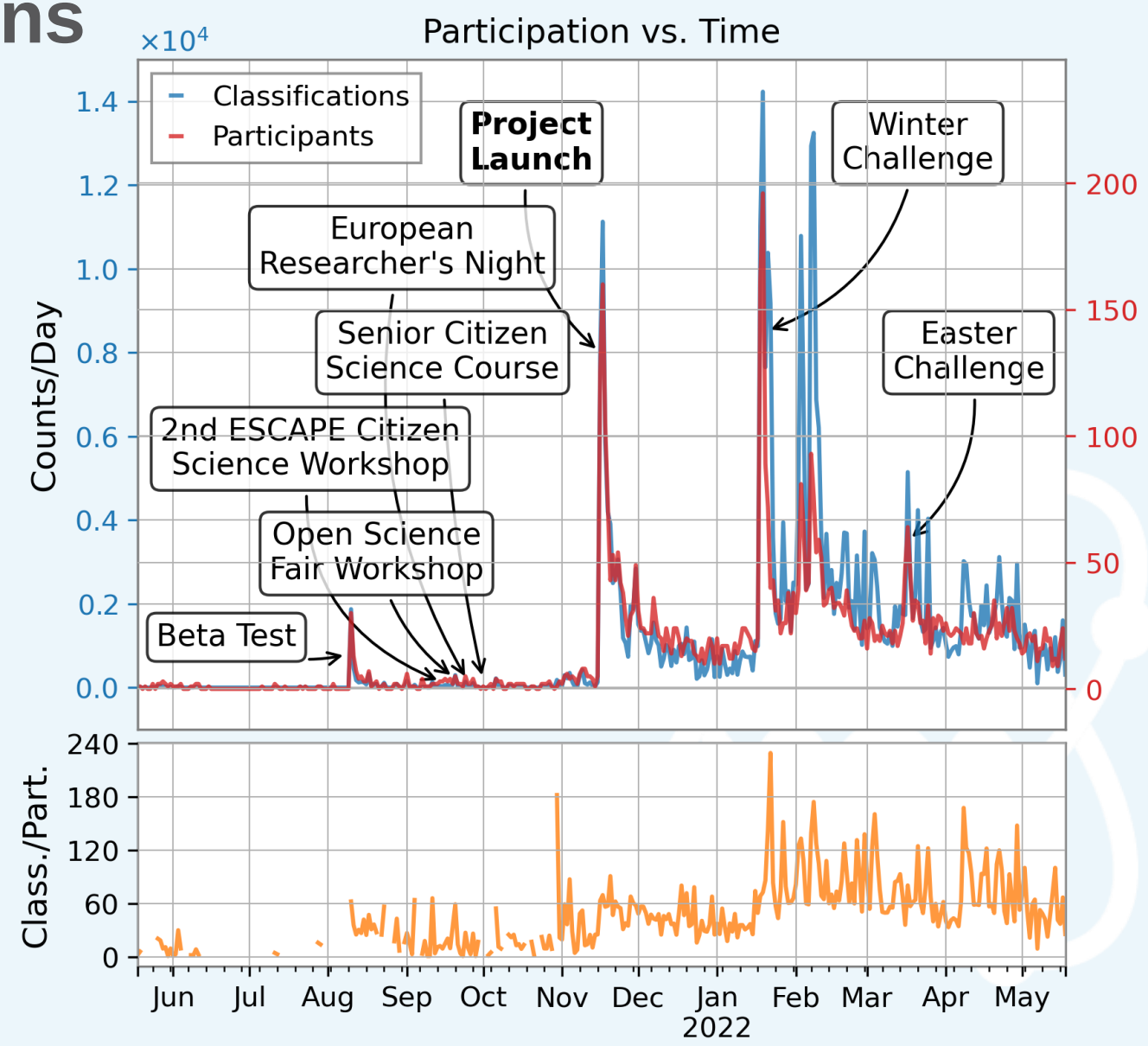
Retirement limit: 12
Images retired: 10,522 / 20,221
Classifications: 159,985 / 242,652
ETC* 53 days



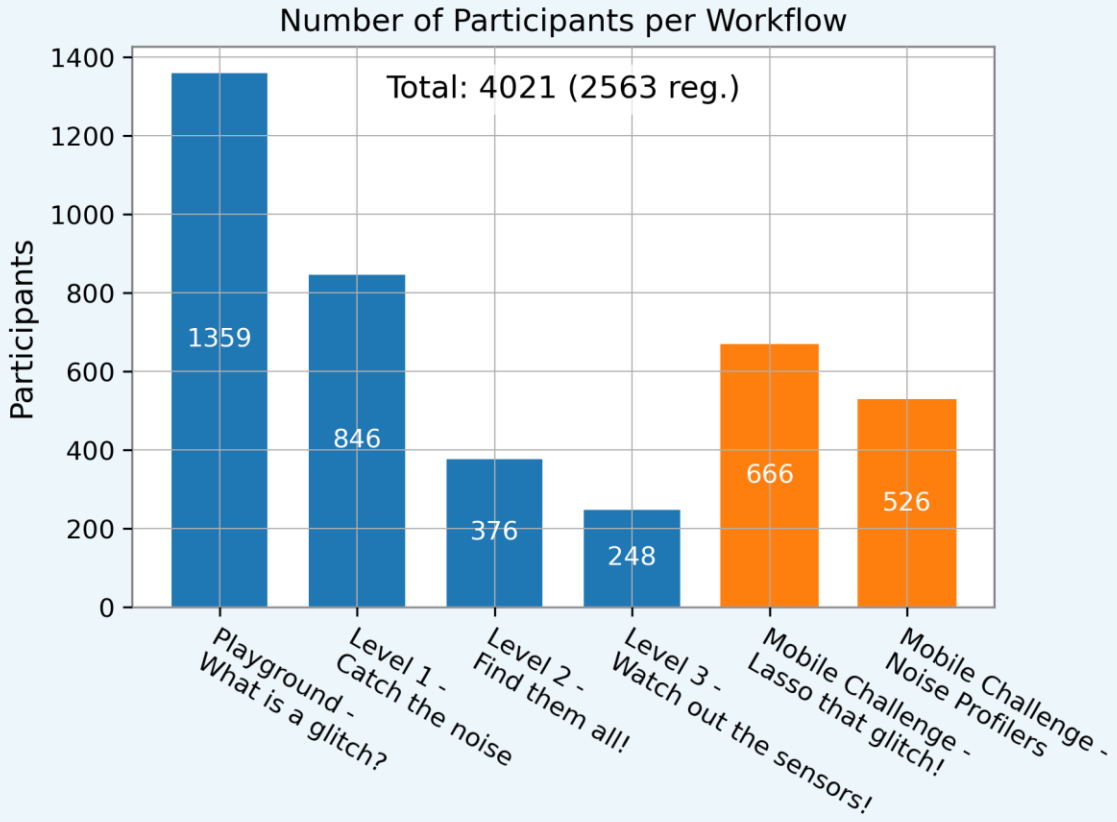
Engaging citizens

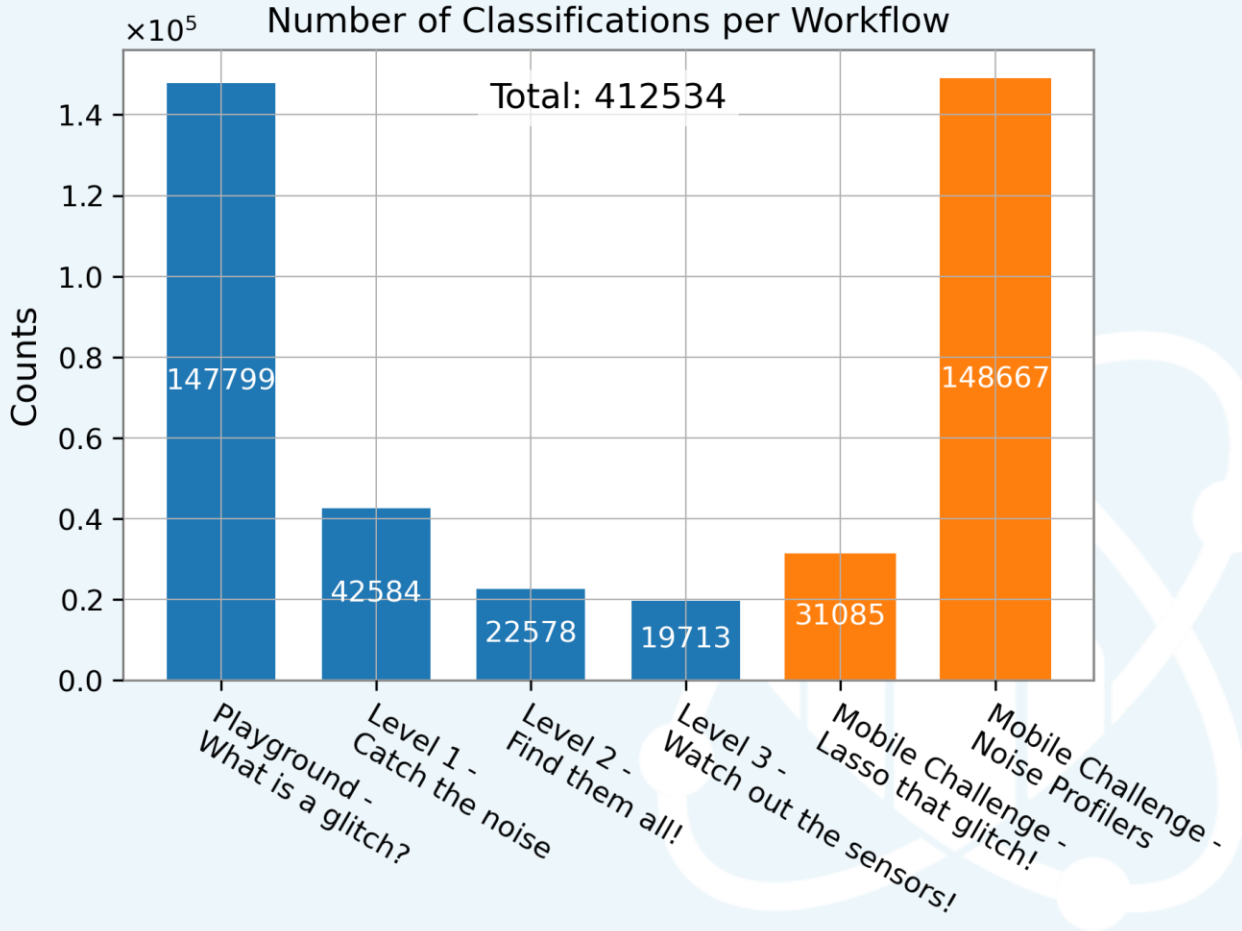
Many initiatives to promote the project

- Winter/Easter challenges
- Dedicated Workshops
- Events
- Courses



Processed data





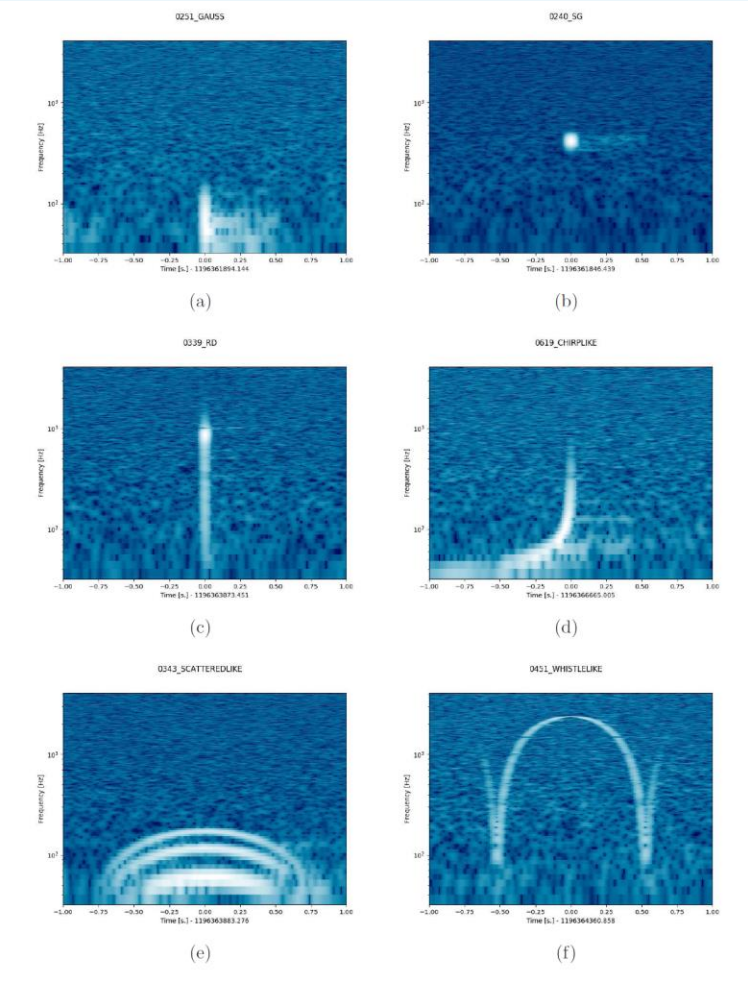
Machine Learning processing

CNN for automatic classification

- First step of a multi-stage pipeline (including other tasks)

Checks and development on simulations

- Previous works as input steps
- Deep, multi-layer structure
- Developed in Python + standard libraries (tensorflow,Keras)
- Run on GPUs

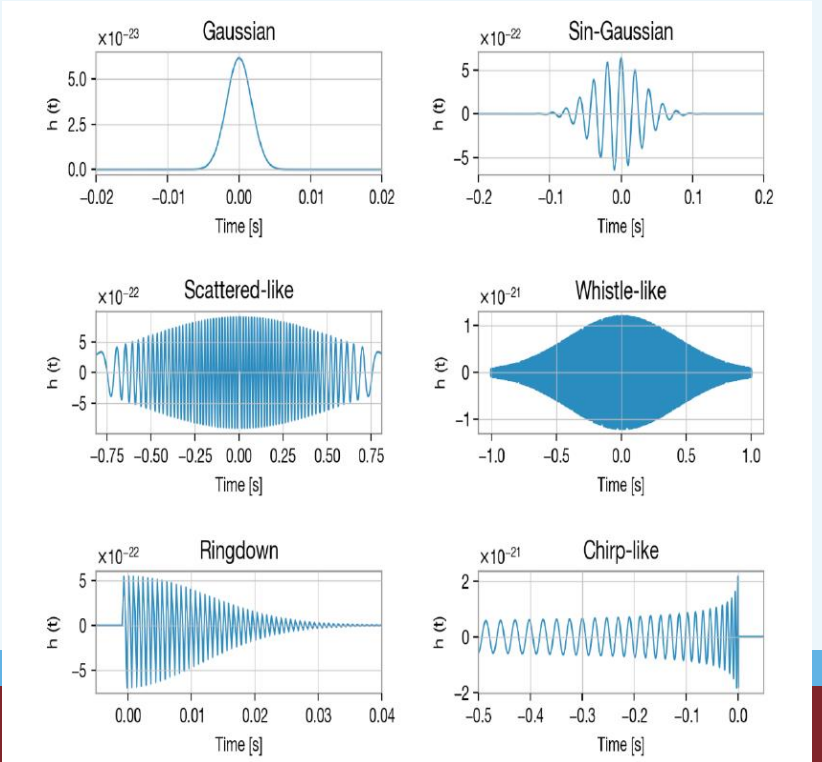


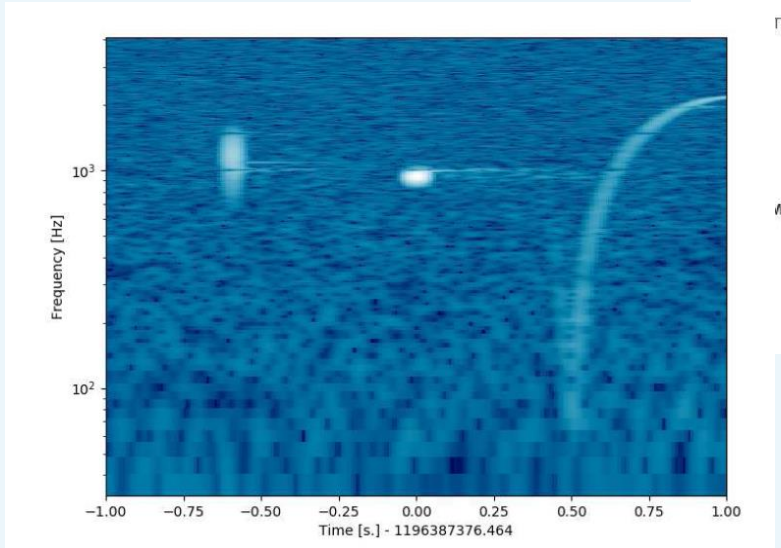
Razzano&Cuoco, 2018

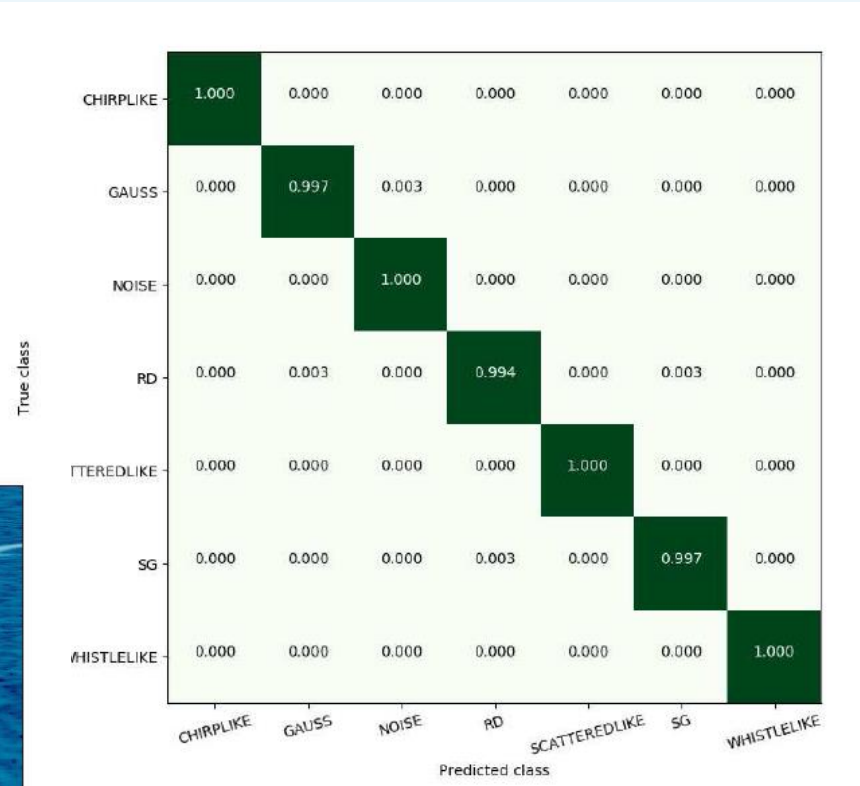
Machine Learning processing

2D vs 1D

- 2D good results, both on simulations and previously labeled real data
- Convolutions robust for multi-glitch situations
- Image-building (little) time consuming, tried 1D CNN







Razzano&Cuoco, 2018

Talpini&Razzano, 2021

The road ahead

- **GWitchHunters project on Zooniverse**
  - Successfully launched: we keep monitoring the data inflow
  - New datasets included, more challenges to come

- **Data Analysis**
  - We have started the first analysis using the data collected so far
  - Development based on simulations
  - Comparison CNN/human in progress
  - Not only classifications, processing regression and localization

- **Next steps**
  - Add new glitch datasets & new auxiliary channels
  - Offer novel challenges for data exploration & noise hunting

Stay Tuned
(& classify glitches!)

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