REINFORCE

REsearch INfrastructures FOR Citizens in Europe

Gravitational Wave Noise Hunting

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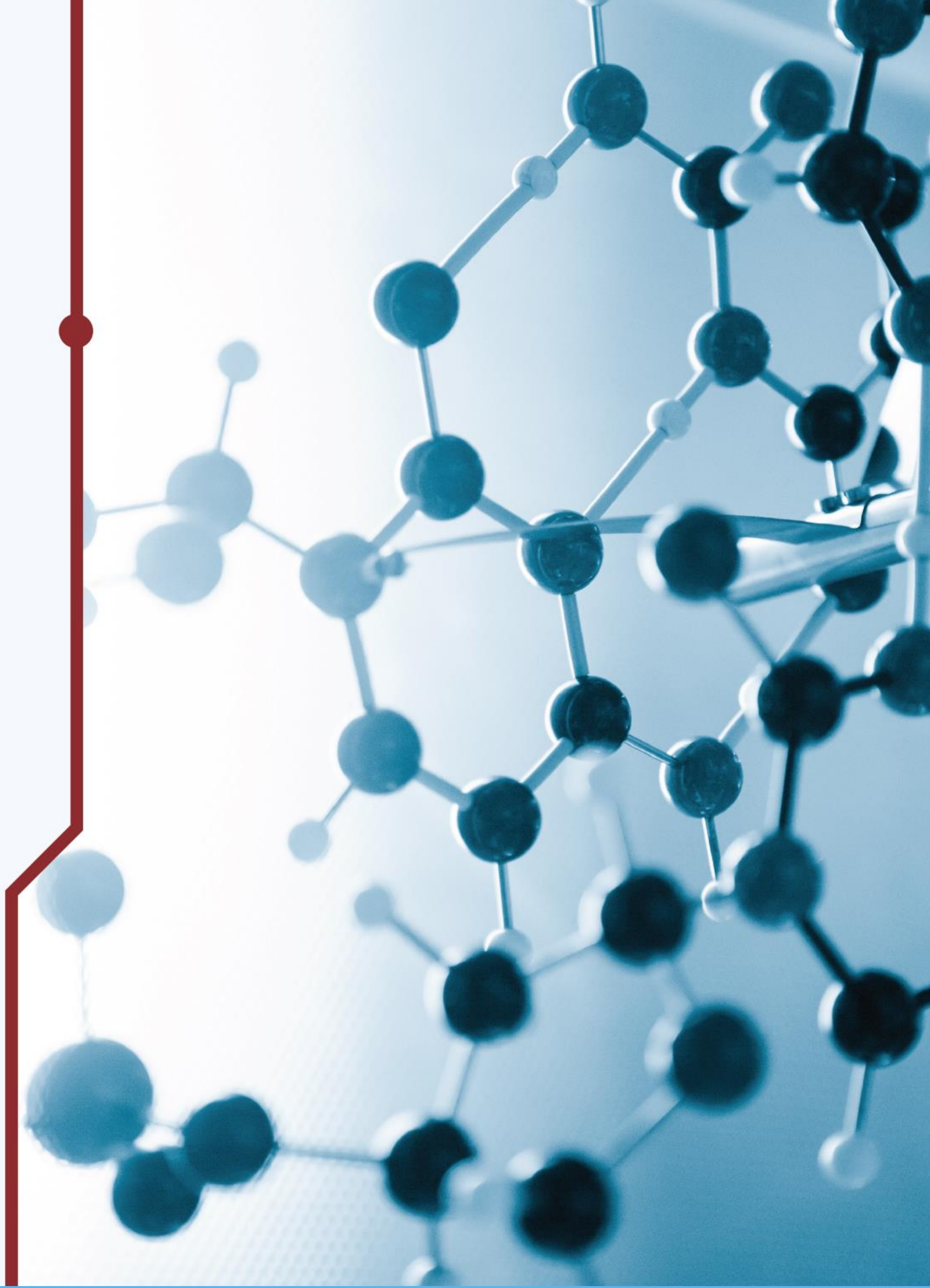
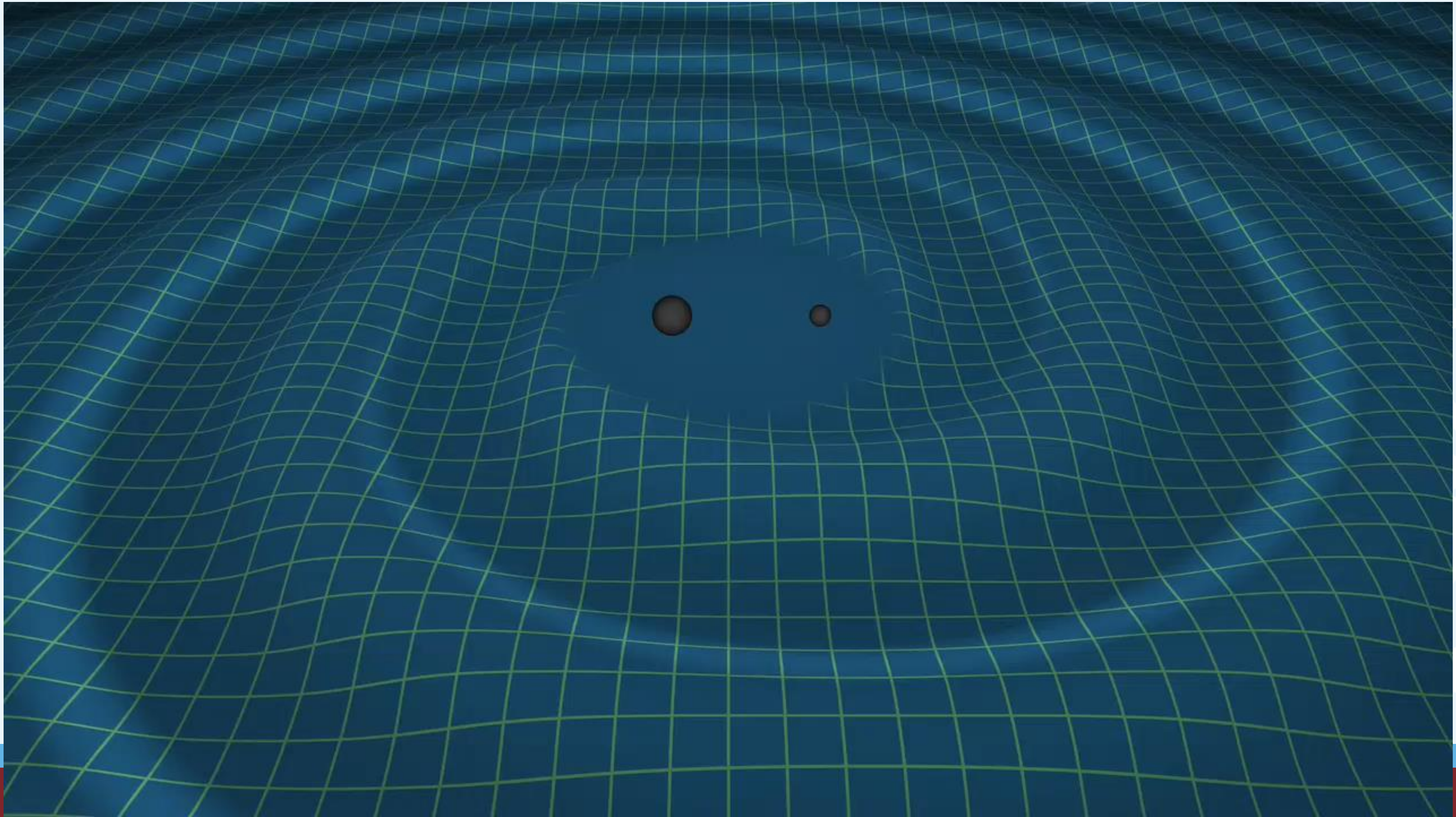
On behalf of the REINFORCE-WP3

Webinar “How to help Scientists in the Gravitational Wave hunt”

15 October 2020



When two black holes collide…



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 light
  - Now we can detect gravitational waves
  - Cosmic messengers carrying complementary information

Gravitational Waves – a timeline

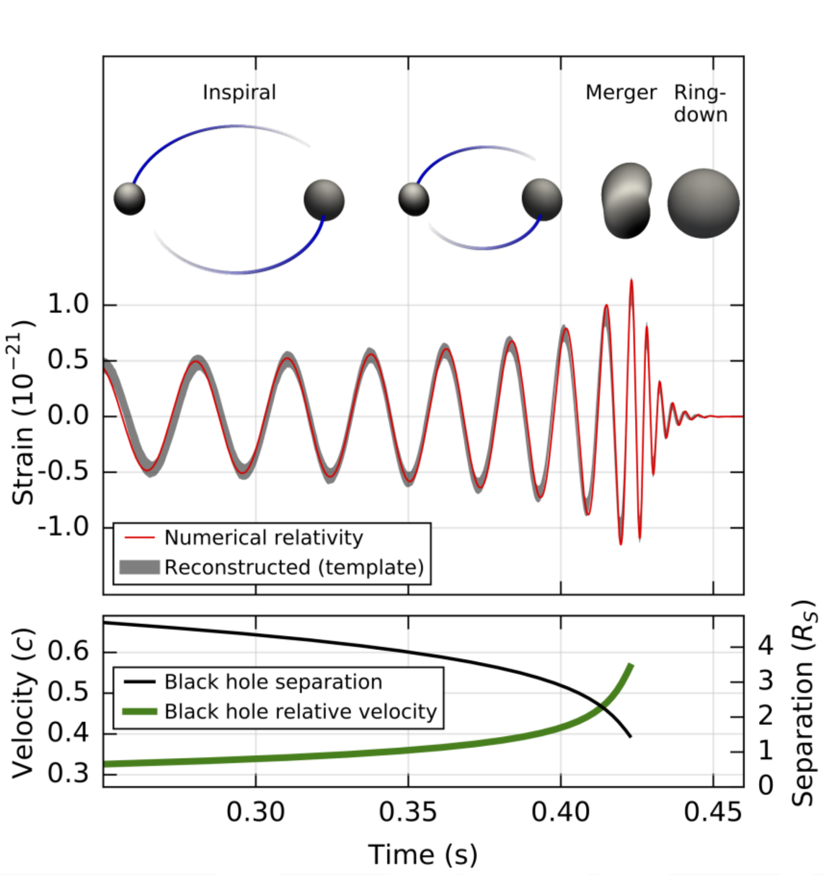
- **1915:** Einstein's general relativity (new theory of gravity)
- **1916:** Einstein's prediction of gravitational waves from general relativity
- **1968:** First attempts of detection by Joseph Weber (USA). Era of resonant antenna
- **1972:** First tests on detectors based on interferometry (USA)
- **1981:** Start of studies in Italy on interferometry by Adalberto Giazotto
- **1984:** Laser Interferometer Gravitational Wave (LIGO) project funded in USA
- **1993:** Approval of Virgo project
- **1999:** Inauguration of LIGO detectors
- **2003:** Inauguration of Virgo detector
- **2007-2011:** Joint LIGO-Virgo observing runs
- **2011-2015:** Development of Advanced detectors (aiming at x10 sensitivity)
- **2015:** First detection of binary black hole GW (observing run O1)
- **2017:** Advanced Virgo joins LIGO in observing run O2. First detection of binary neutron star (17 Aug)
- **2019-2020:** Third observing run (O3)

Sources of Gravitational Waves

- **What are gravitational waves?**
  - Ripples in spacetime traveling at the speed of light
  - Produced by acceleration or asymmetry of masses
  - Violent phenomena (cosmic explosions, collisions, etc)

- **Transient sources**
  - Coalescence of compact binary systems (black holes or neutron stars) – Detected!
  - Supernovae - expected
  - Others? - expected

- **Continuous sources**
  - Periodic emission from rotating neutron stars (pulsars) – expected
  - Continuous stochastic background – expected
  - Others? - expected

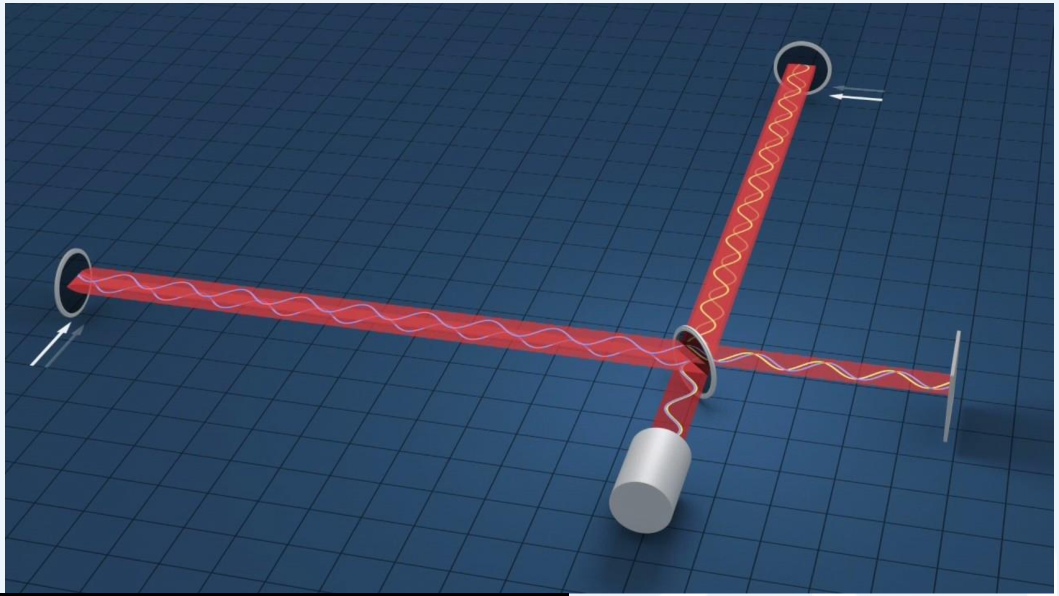


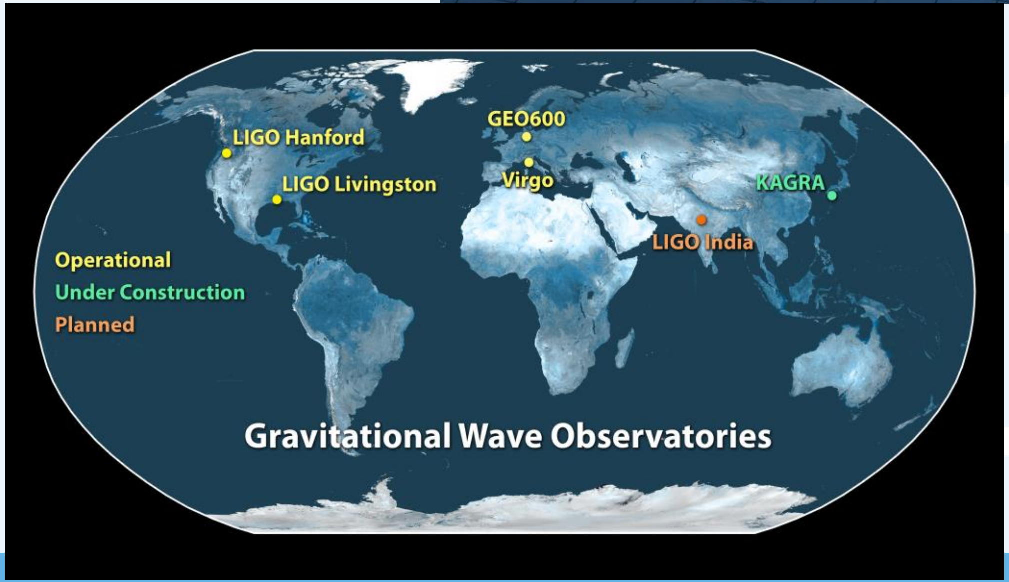
Abbott et al, 2016

How to detect Gravitational Waves?

- **Extremely tiny signals**
  - Typical GW sources induce a deformation of 10^{-18} m over a length of ~1 km
  - High background noise

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

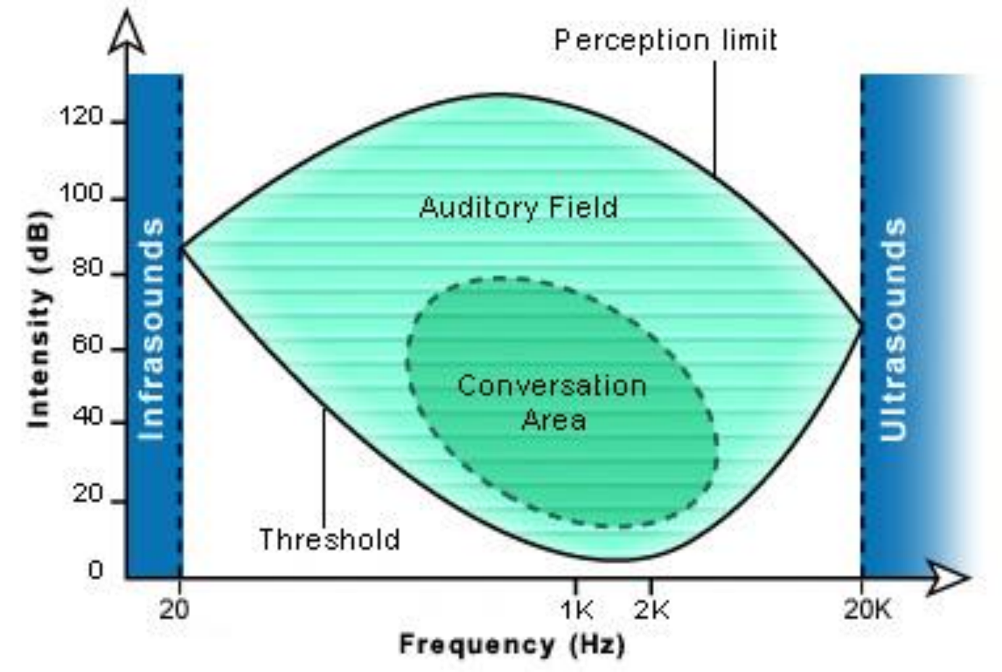


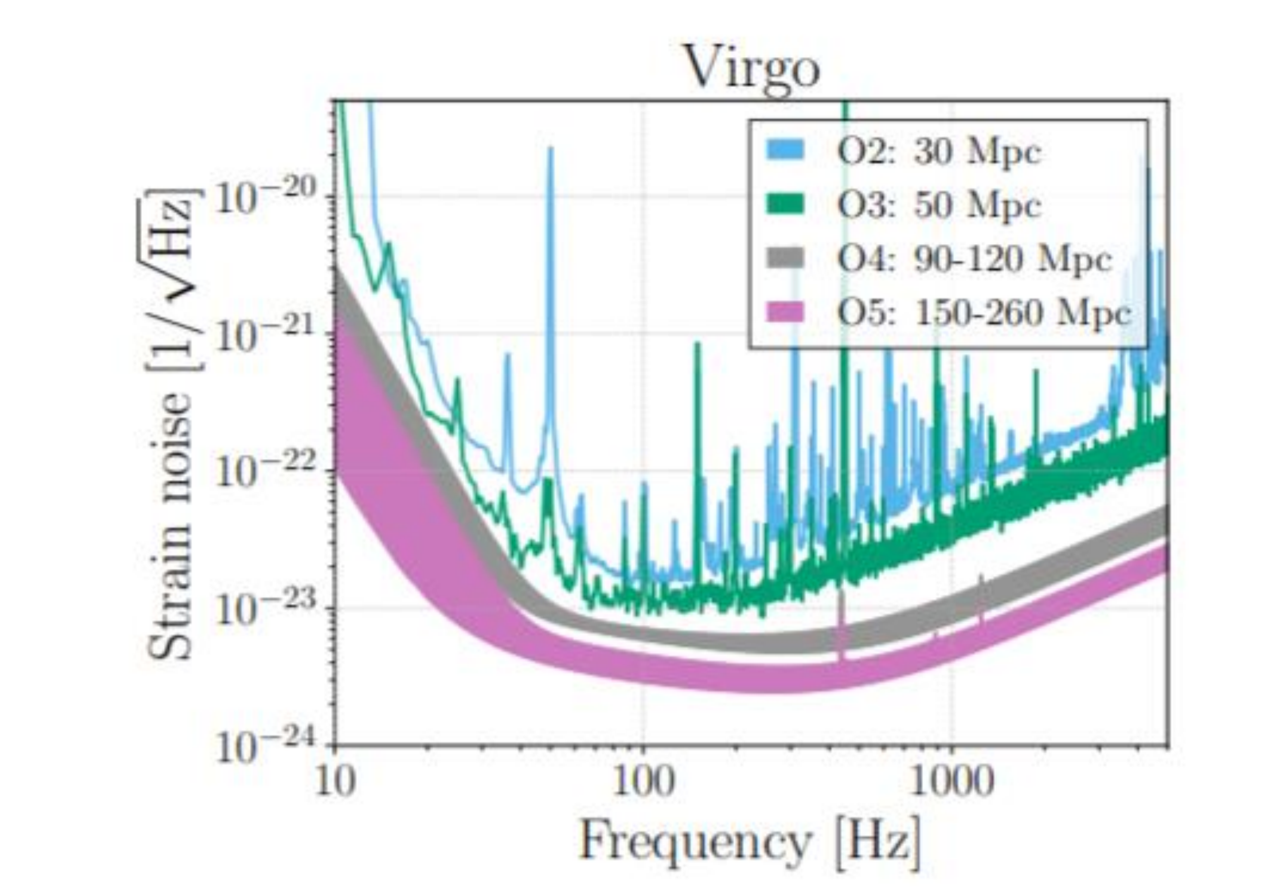


Credits: LIGO

Detecting Gravitational Waves

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



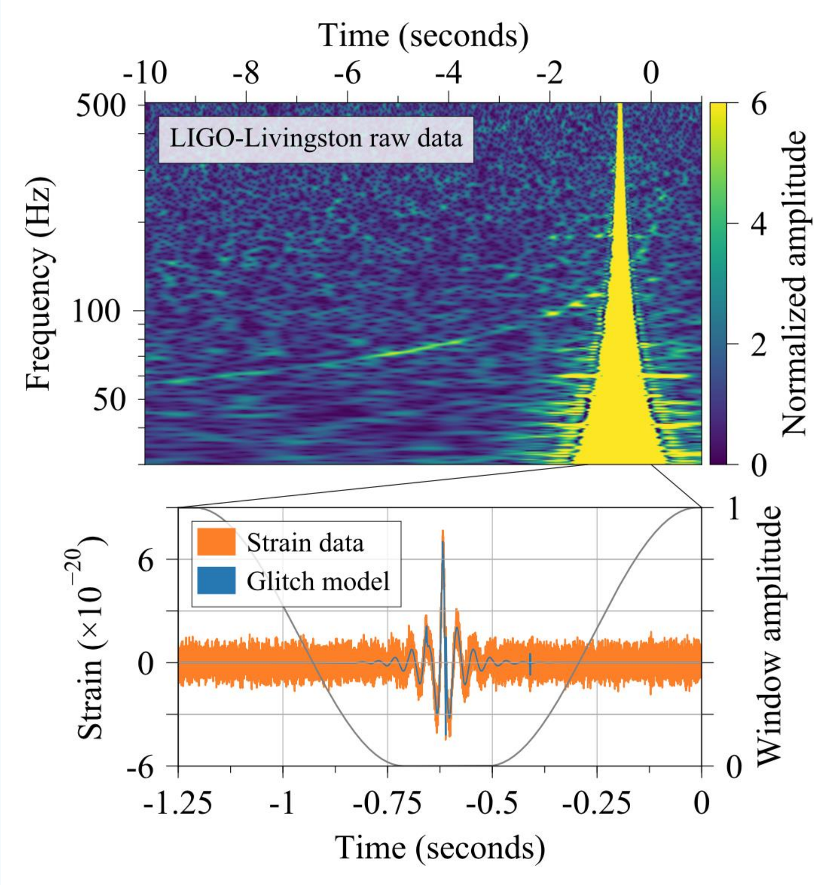


Abbott et al 2016

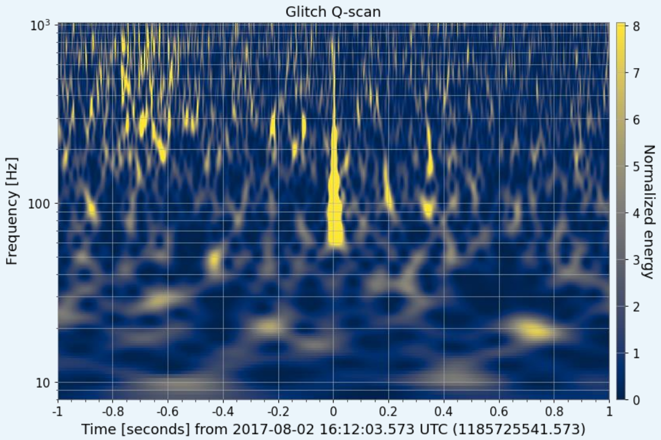
Noise glitches

- **Noise is not stationary in time**
  - Transient events can happen
  - Not related to astrophysical source, but local disturbances
  - Affect data quality and detection

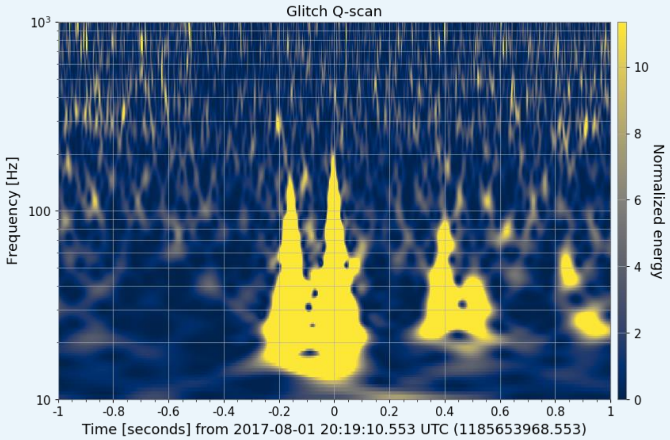
- **Noise hunting & characterization is critical**
  - Detect and classify glitches to find origin and remove them
  - Glitches have complex morphology
  - Machine learning shows promising approaches



Glitch in LIGO L1 detector during GW170817 Abbott et al 2017



Blip glitch

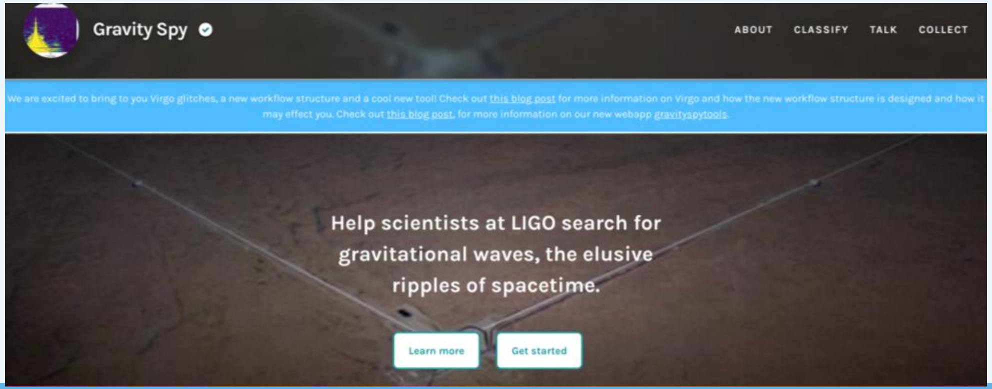


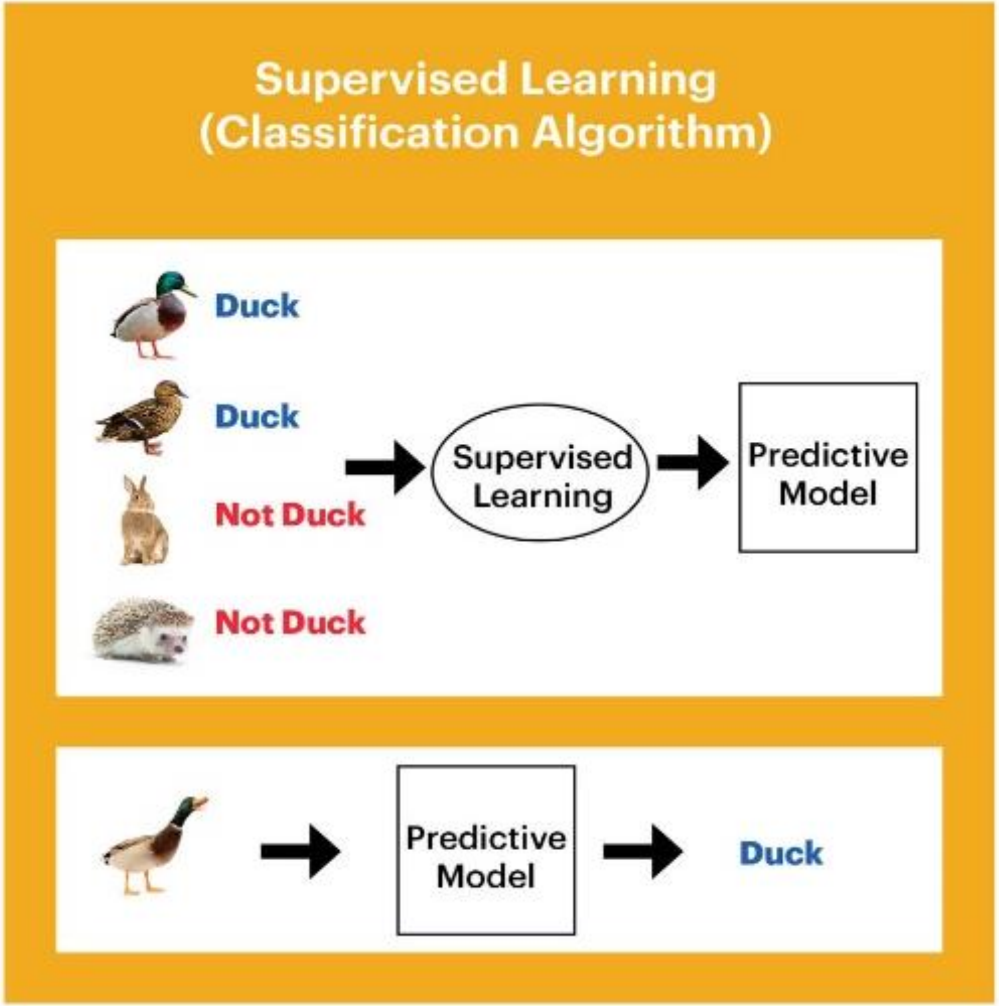
«Millenium Falcon» glitch ?

Glitches & citizen science

- **Machine Learning approach**
  - Promising to classify complex time-frequency patterns of glitches
  - Large input required to train machine learning models
  - Input from citizen science can be very important

- **Citizen scientists can help!**
  - Look at glitches & other noise sources and help characterizing them
  - Success story: Gravity Spy on Zooniverse (2016)





Credits: Western Digital

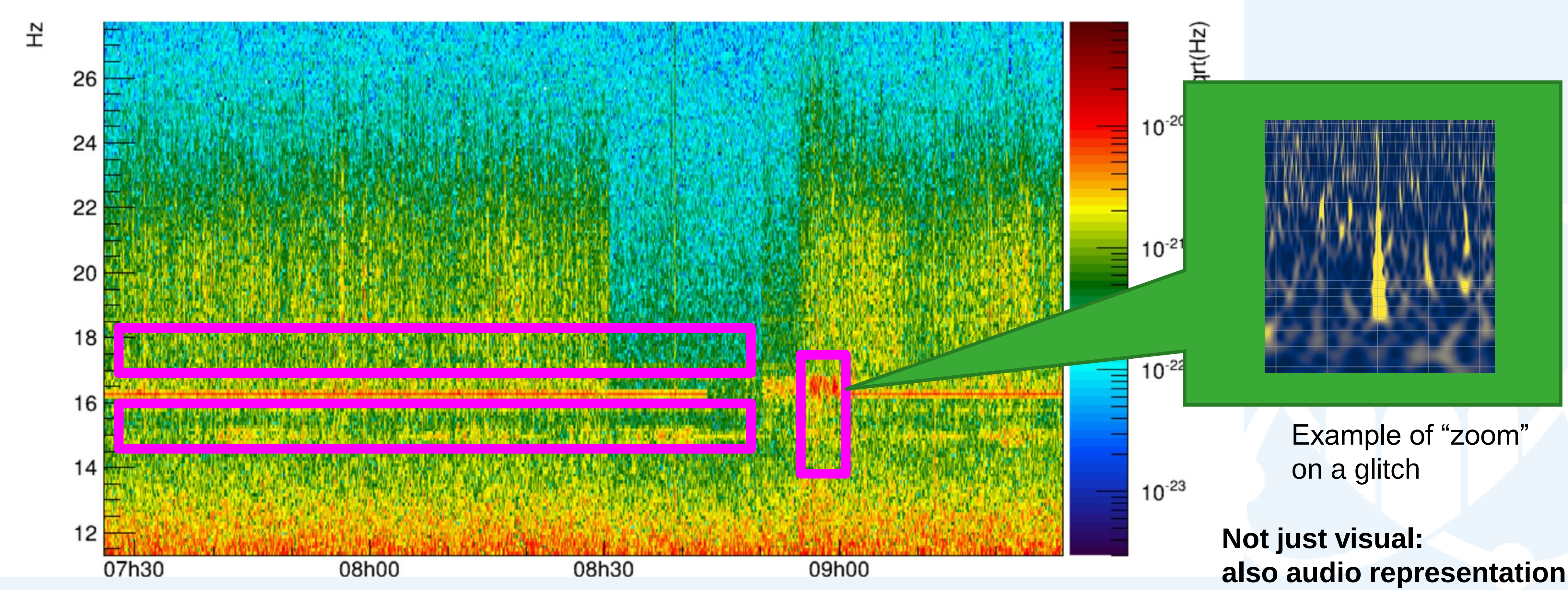
GW noise hunting in REINFORCE

- **Noise hunting & citizen science**
  - Citizens can contribute to noise identification and classification
  - A specific “demonstrator” project has been developed within REINFORCE
  - Involving Unipi, EGO, EA, CONICET, OU, UOXF

- **Share findings and find new features**
  - Will use real data from GW detectors (Virgo, LIGO)
  - Not only identification of known noise features.
  - Citizens will contribute to unveil new, rare glitches not yet identified
  - Data will be presented via time-frequency representations and sounds

Investigating the noise

More sensitive instruments → More glitches → More need to remove them



From Virgo logbook

Example of “zoom” on a glitch

Not just visual:
also audio representation will be used

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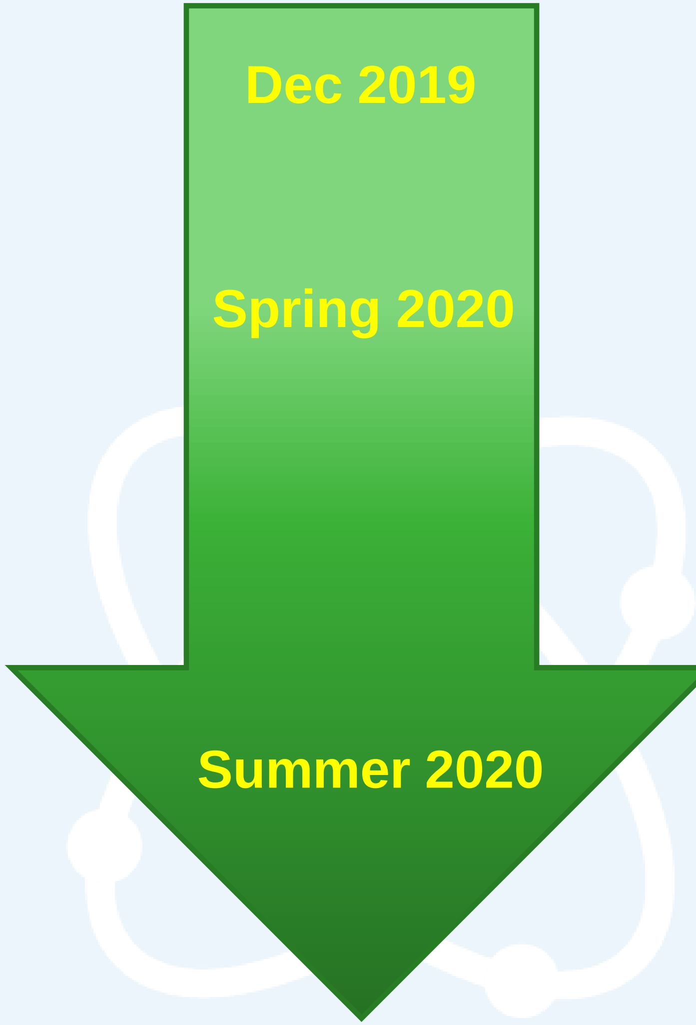
The road ahead - I

- **Start !**

- **Establish data selection & Format**
  - Select data from LIGO and Virgo stream
  - Filter good time intervals of data
  - Develop flexible data format
  - Identify optimal visual and audio filtering

- **Dataset creation**
  - Select a statistically significative representation of data
  - Create visual and sound representation



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The road ahead - II

- **Developing and deploying Zooniverse website**
  - Prototype and sample tasks
  - Prepare documentation, guides
  - Open communication channels (e.g. blog, social)

- **Developing the ML algorithms**
  - Machine learning for classification
  - Optimize classification parameters using inputs from citizen scientists

- **Launch the website!**

- **Comparative analysis**
  - Performance of human vs machine learning
  - Sound vs visual representation
  - Impact on science

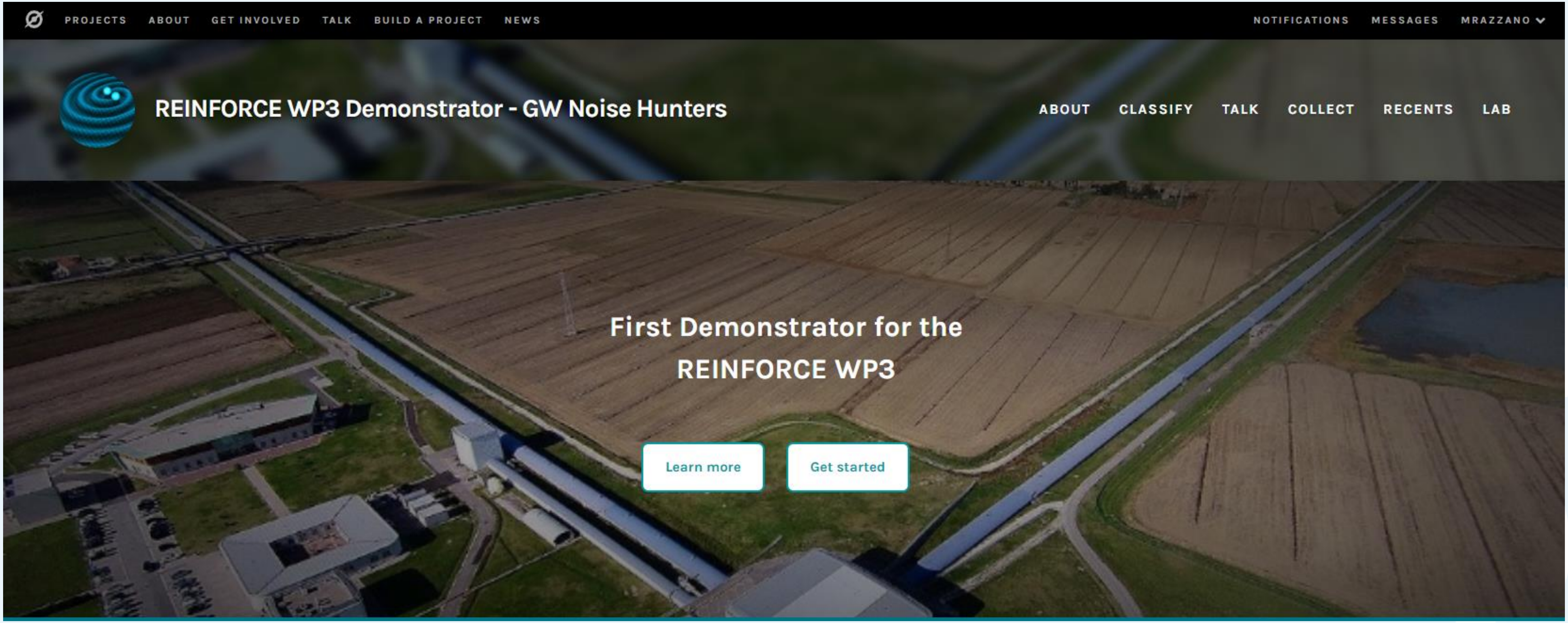
Fall 2020

Fall 2020

Spring/summer 2021

Summer 2022

Demonstrator Teaser



Conclusions

- Gravitational wave physics is a new, evolving field of science
- Big amount of data, contribution in analysis is welcome!
- Less noise → More sensitivity → More events → More science!
- New GW demonstrator in progress, ready for launch in 2021