Multi Messenger data analysis challenges in the EOSC framework

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European Gravitational Observatory & Scuola Normale Superiore, Pisa

Second Gravi-Gamma Workshop 23-25 June 2021

EGO - Virgo

SCUOLA NORMALE SUPERIORE

European Open Science Cloud (EOSC) framework

EUROPEAN OPEN SCIENCE CLOUD

The European Open Science Cloud (EOSC) is an environment for hosting and processing research data to support EU science.

Trusted, virtual, federated environment

FAIR data principles: Findable Accesible Interoperable Reusable

EOSC is a cloud for research data in Europe that allows universal access to data through a single online platform.

EOSC will federate existing resources across national data centres, e-infrastructures, and research infrastructures, allowing researchers and citizens to access and re-use data produced by other scientists.

ESCAPE: European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures

https://www.projectescape.eu/

We bring together the astronomy, astro-particle, particle and nuclear physics communities

ESCAPE cluster main goals

Improve access to data and tools to unlock **innovation** for the society at large.

Build a European cross-border and multi-disciplinary open innovation environment for science, while connecting **EOSC** and ESFRI.

Adoption of **common approaches** for data management

Provide data with **FAIR** principles: Findable, Accessible, Interoperable, Reusable

Facilitate **interdisciplinary** and networked research between different ESF/RI and digital SME

Educate and train the scientific and wider user communities

ESCAPE PARTNERs

The ESCAPE cluster comprises world-class research facilities in astronomy and particle physics. **ELT, CTA, SKA, KM3NeT, EST, HL-LHC, FAIR, JIV-ERIC, LSST, EGO-Virgo.** (Credit: ESCAPE)

ESCAPE Work Programme

Data Lake:
Build a scalable, federated, data infrastructure as the basis of open science for the ESFRI projects within ESCAPE.

Software Repository:
Repository of "scientific software" as a major component of the “data” to be curated in EOSC.

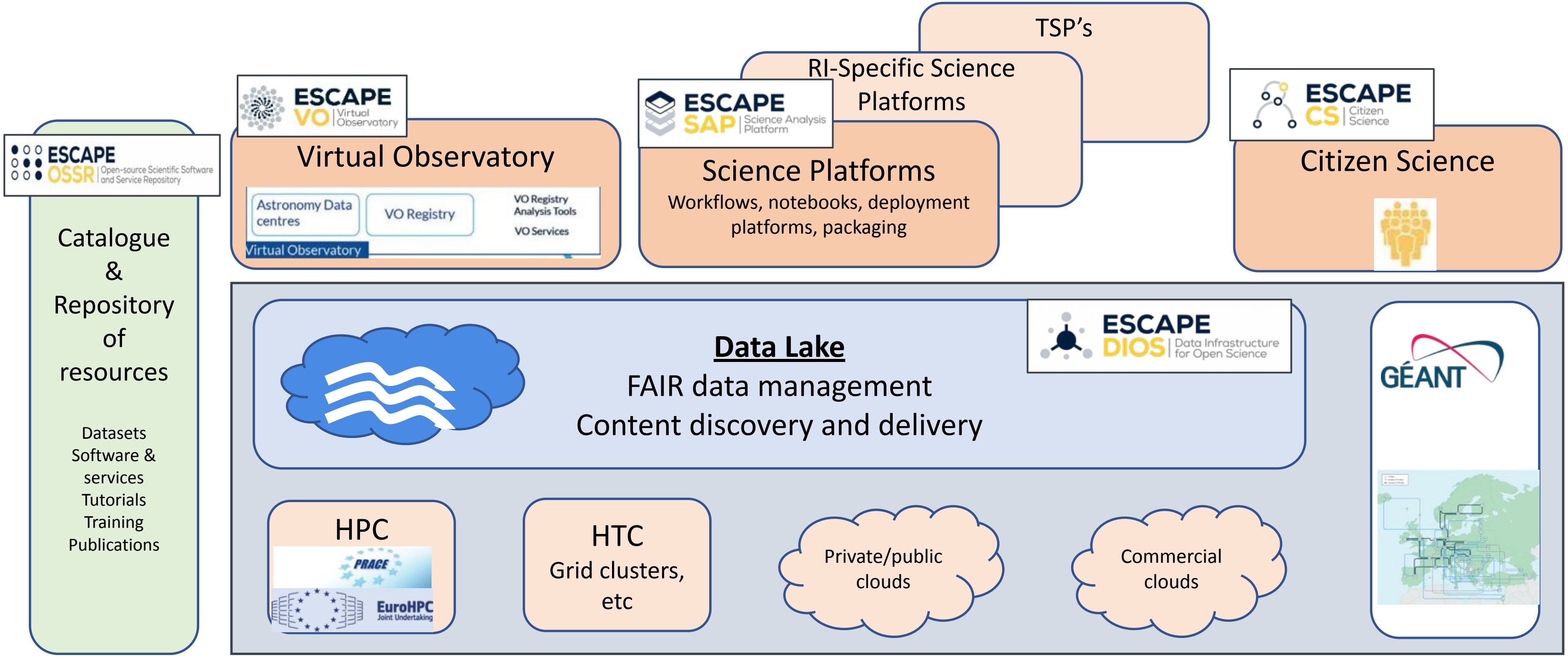
Virtual Observatory:
Extend the VO *FAIR* standards, methods and to a broader scientific context; prepare the VO to interface the large data volumes of next facilities.

Science Platforms:
Flexible science platforms to enable the open data analysis tailored by and for each facility as well as a global one for transversal workflows.

Citizen Science:
Open gateway for citizen science on ESCAPE data archives and ESFRI community

ESCAPE as EOSC cell

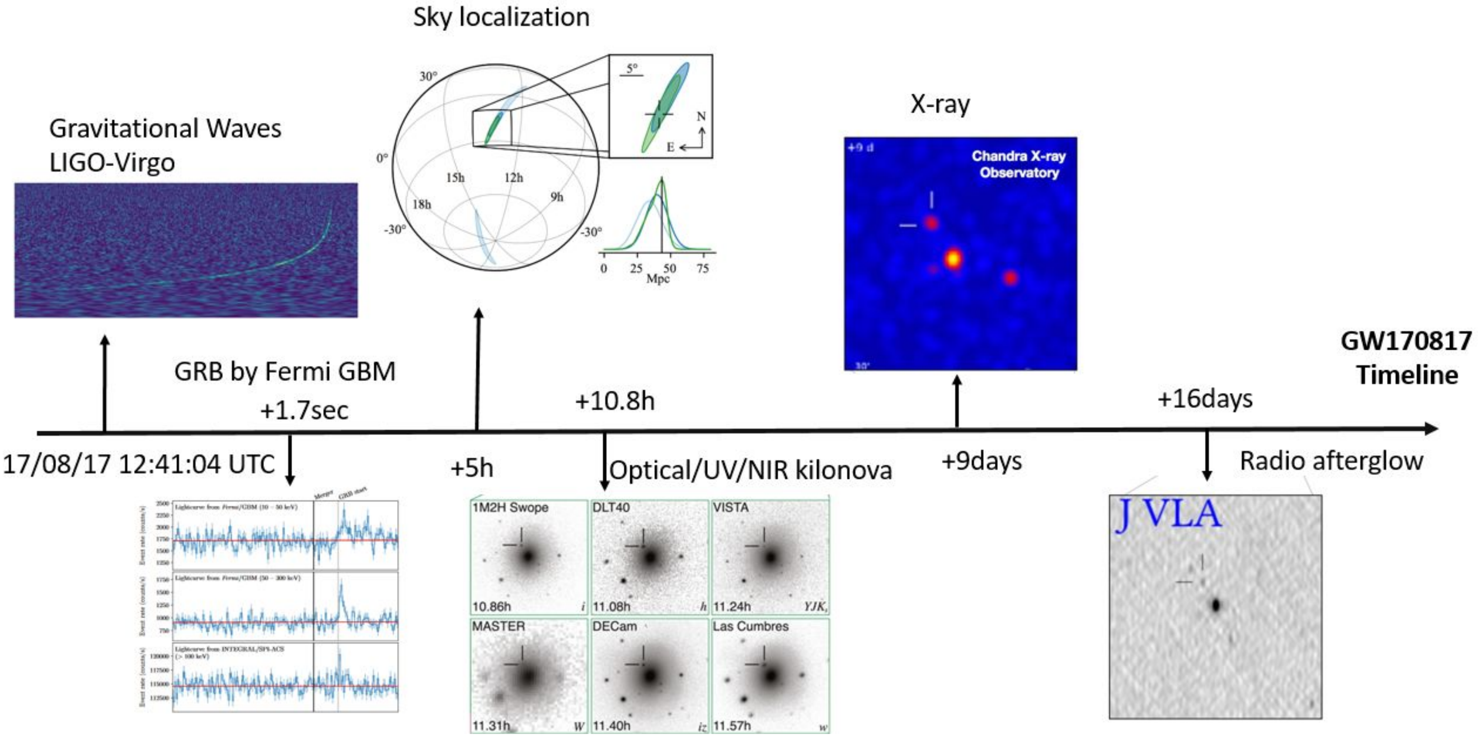
Promoting, implementing and committing to ***Open Science***



Multi-messenger challenges

in EOSC framework

GW170817 detection and EM follow up



Gravitational Waves & Multimessenger astronomy

- **Short GRB**
  Fermi GBM, INTEGRAL, Astrosat, IPN, Insight-HXMT, Swift, AGILE, CALET, H.E.S.S., HAWC, Konus-Wind
- **Gravitational waves (well-modeled)**
  Ligo/Virgo

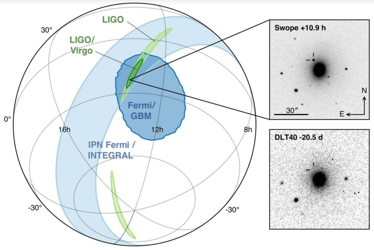
EARLY TRIGGERS
(sec to mins)

- **X-Ray**
  Swift, MAXI/GSC, NuSTAR, Chandra, Integral
- **UV**
  Swift, HST
- **RADIO**
  ATCA, VLA, ASKAP, VLBA, GMRT, MWA, LOFAR, LWA, ALMA, OVRO, EVN, e-MERLIN, MeerKAT, Parkes, SRT, Effelsberg
- **IR**
  REM-ROS2, VISTA, Gemini-South, 2MASS, SPITZER, NTT, GROND, SOAR, NOT, ESO-VLT, Kanata Telescope, HST
- **Optical**
  Swope, DECam, DLT40, MASTER, VISTA, ESO-VLT + others

BROADBAND FOLLOW-UP
(hrs to days)

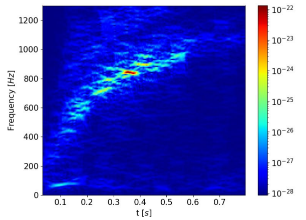
Binary Neutron Star Merger

- *Fast alert and sky Localization for follow-up study*
- *Better understanding of physical processes (e.g. heavy-element nucleosynthesis)*



Abbott et al. (2017)

- **Neutrinos**
  (prompt emission of ~ 90% of total CCSNe energy)
  IceCube, ANTARES, Pierre Auger Observatory
- **Gravitational waves**
  (prompt emission, unknown waveform, carry little energy)
  Ligo/Virgo



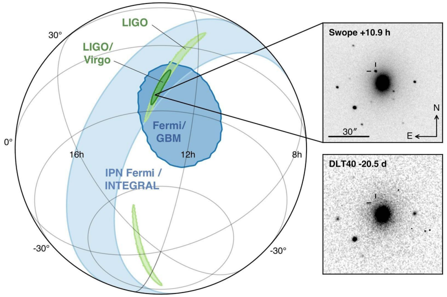
Iess et al. (2020)

- **E.M. emission** (delayed emission)

Core-Collapse Supernovae

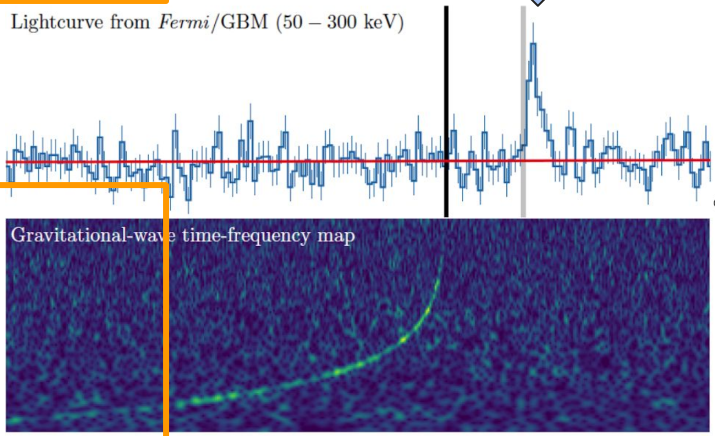
- *Shed Light on explosion mechanism (neutrino-driven, MHD, acoustic)*
- *Information on physical characteristics of progenitor star (mass, rotation)*
- *Information on proto-neutron star*

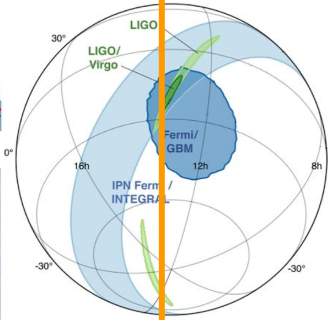
Will be possible Multi-probe real time analysis?



Can we extract information analyzing the heterogeneous data?

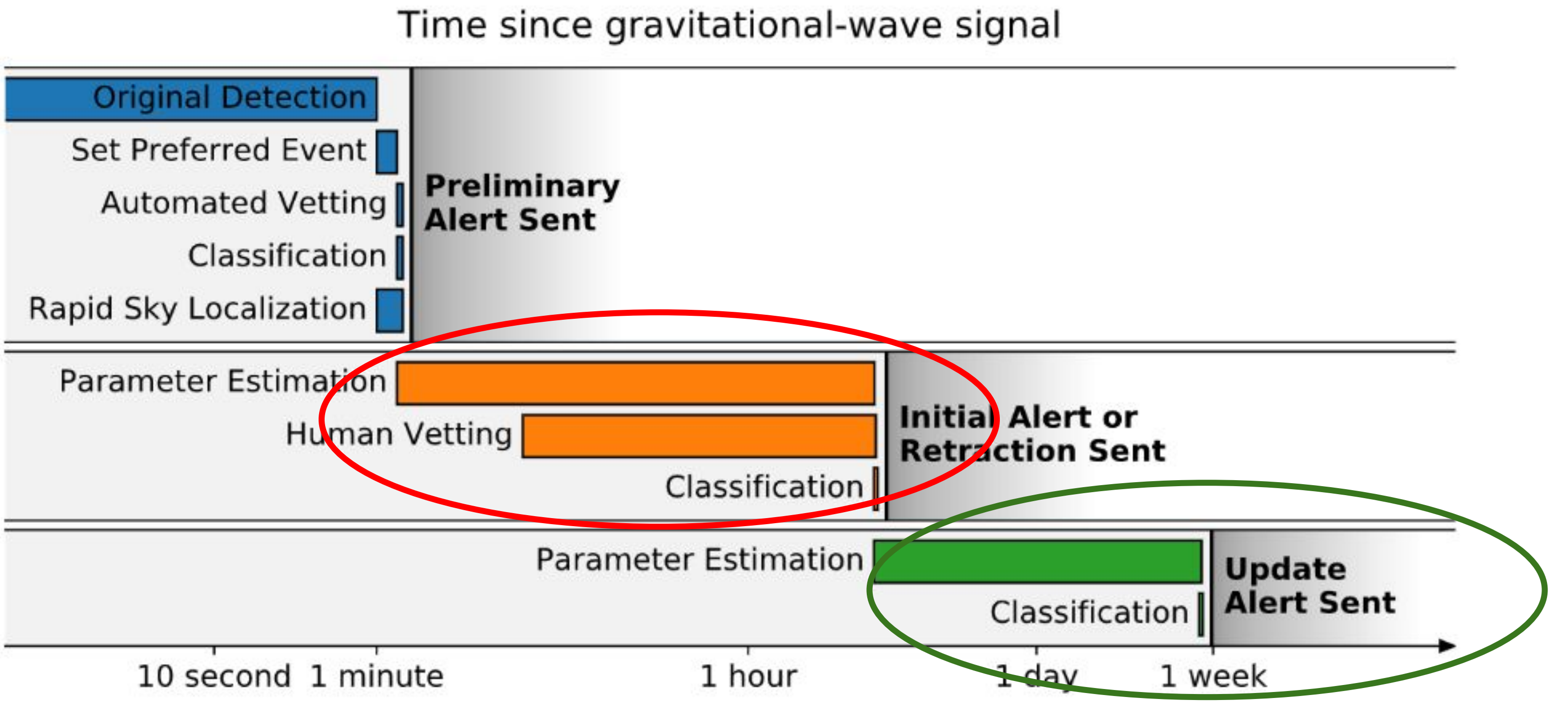
Short GRB event



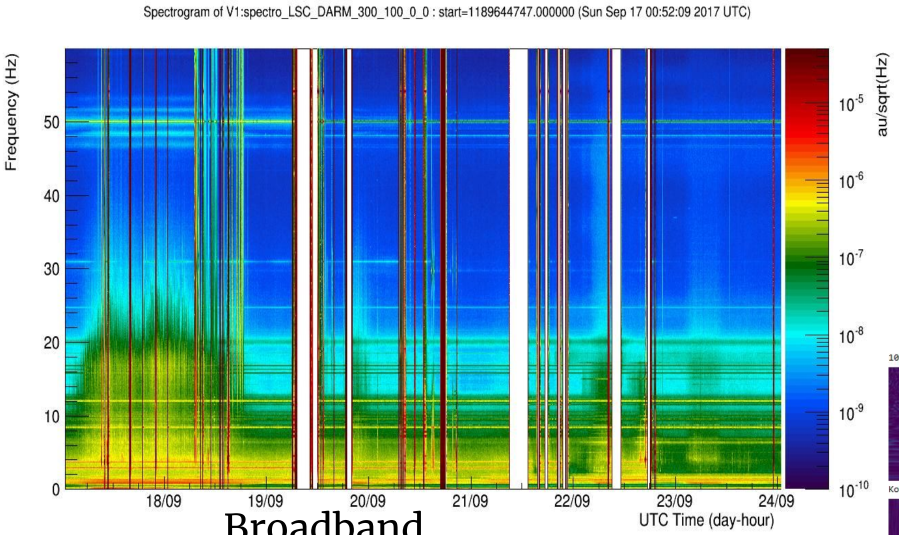


GW event

Gravitational Wave alert system

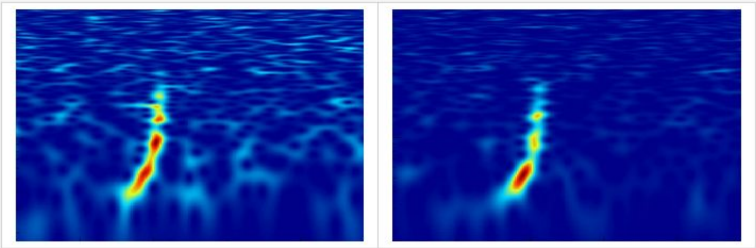


Detector Noise and Signals



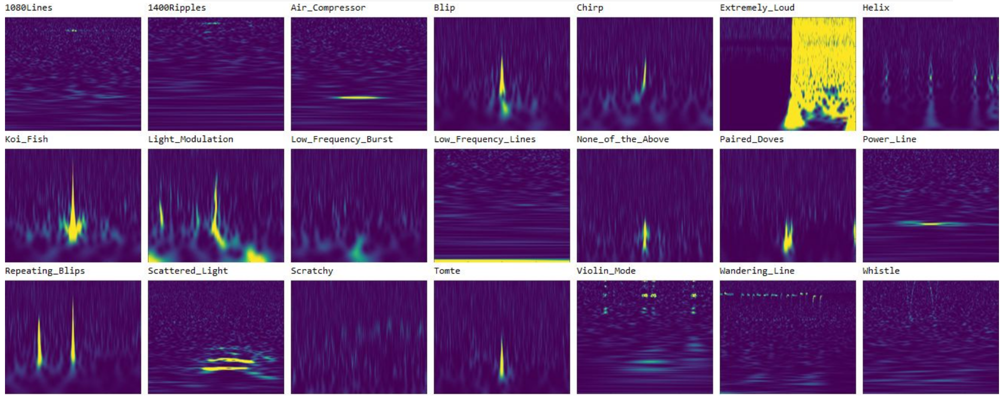
Broadband

Coherent WaveBurst was used in the first direct detection of gravitational waves (GW150914) by LIGO and is used in the ongoing analyses on LIGO and Virgo data.



Time-Frequency maps of GW150914: Livingston data (left), Hanford data (right)

First screenshot of GW150914 event

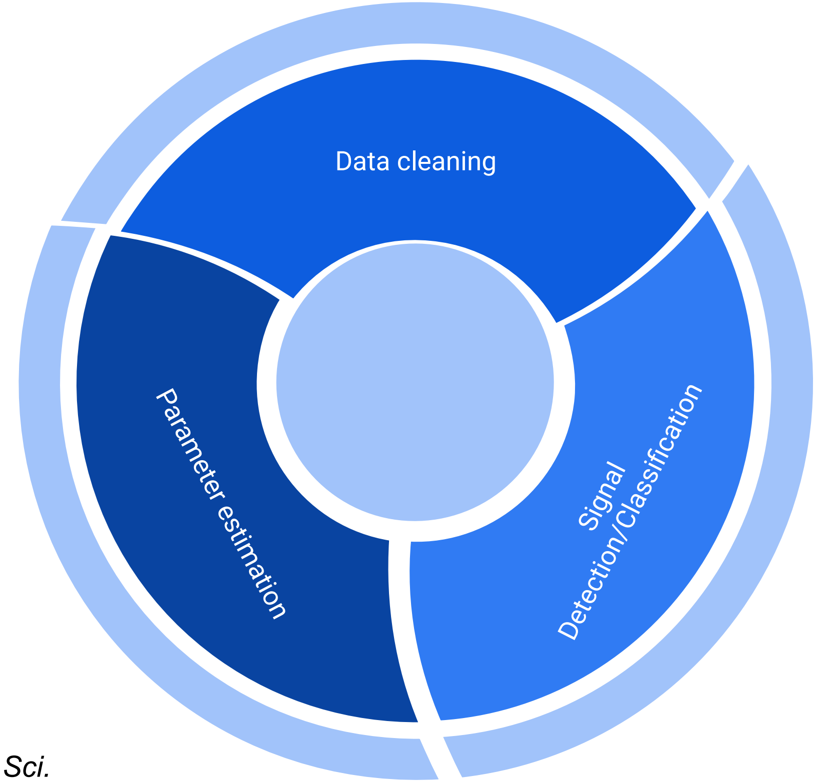


Glitches

Gravity Spy, Zevin et al (2017)

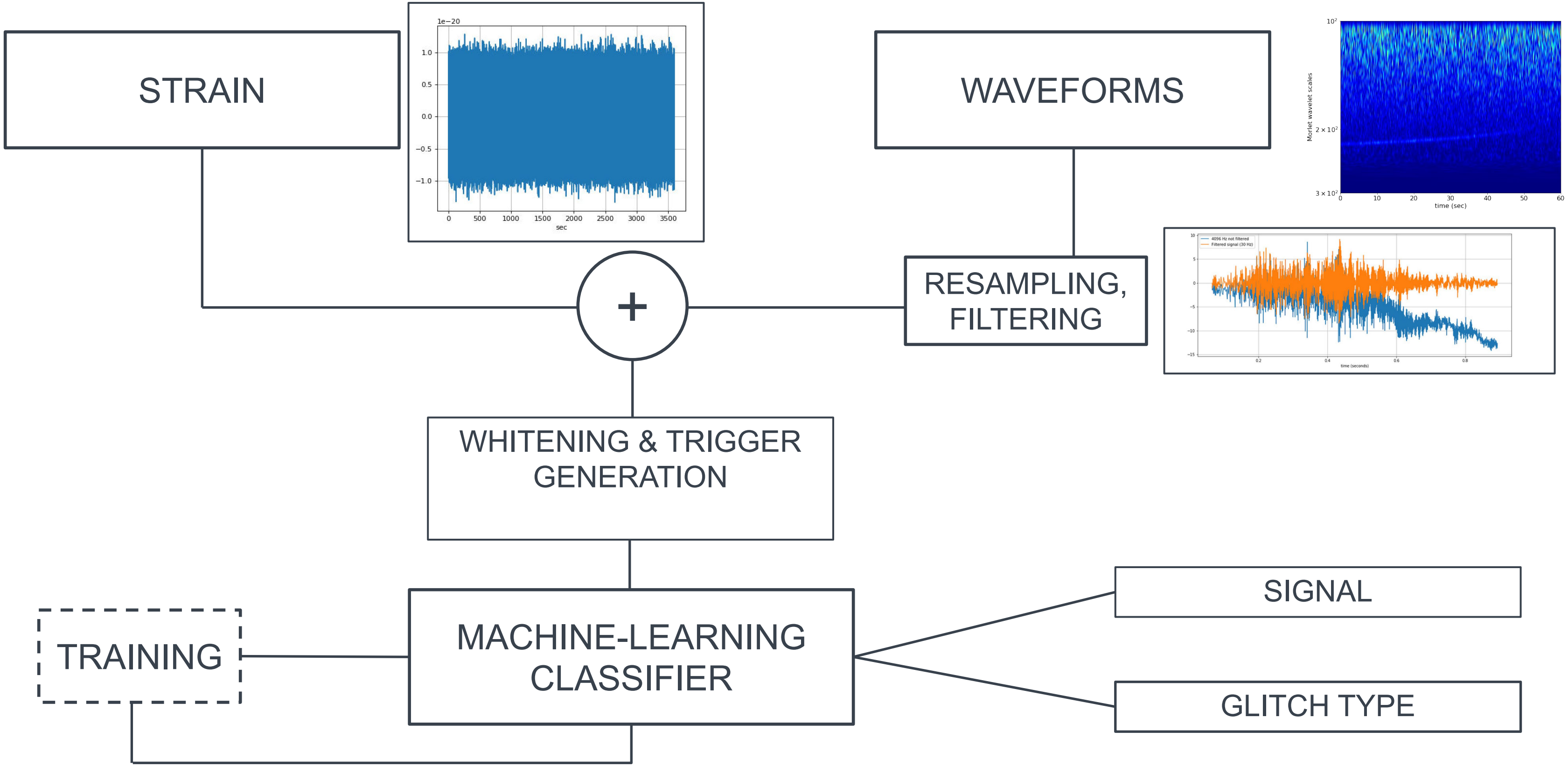
https://www.zooniverse.org/projects/zooniverse/gravity-spy

Machine Learning and real time analysis



Elena Cuoco *et al* 2021 *Mach. Learn.: Sci. Technol.* **2** 011002

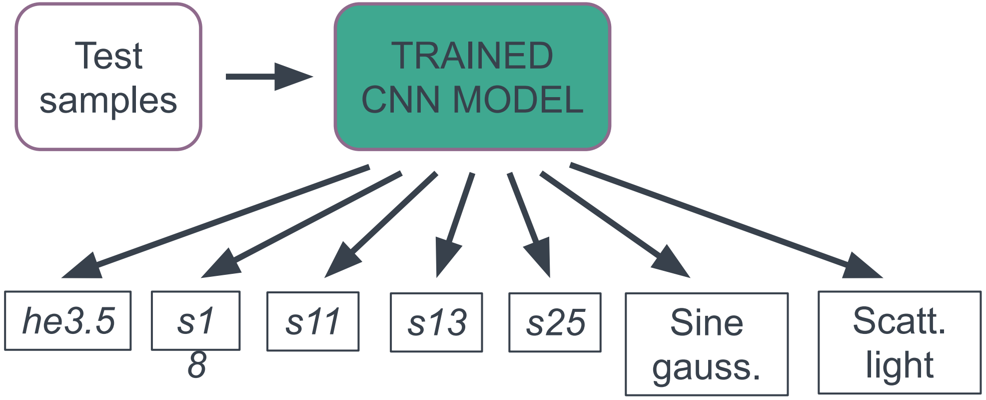
Machine learning GW pipeline workflow



Alberto Iess courtesy

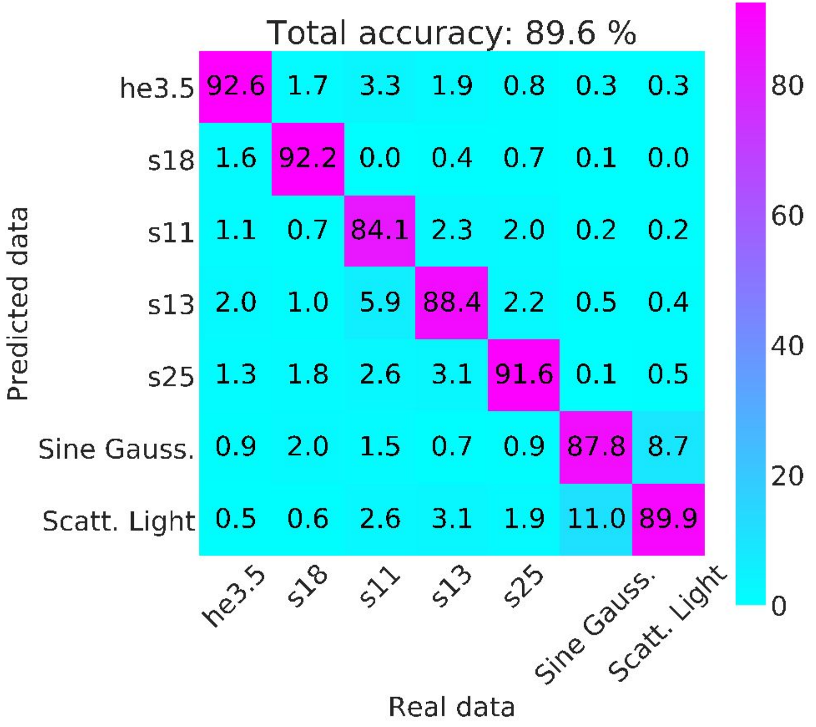
CCSN MultiLabel classification for ET

- Train on **all** (4 CCSNe waveform models + glitches).
- Test on **all.**



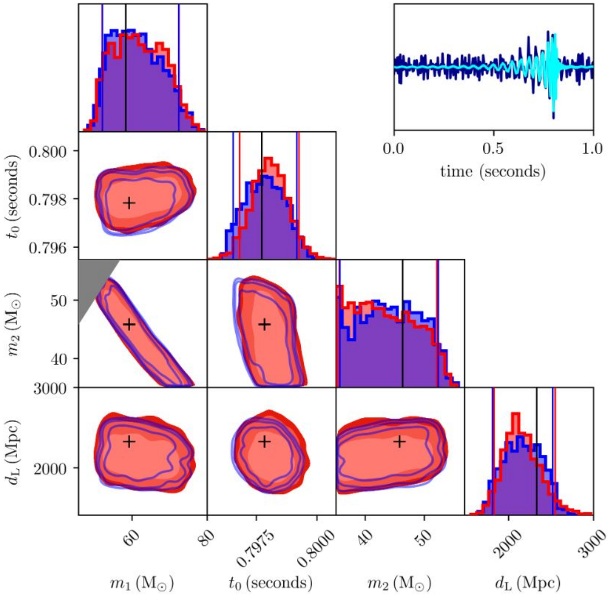
COMPLEX TASK → LONGER TRAINING (> 1 hr)

ET, MERGED 1D & 2D CNN



Alberto Iess *et al* 2020 *Mach. Learn.: Sci. Technol.* **1** 025014

GW signal parameter estimation



Bayesian parameter estimation using conditional variational autoencoders for gravitational-wave astronomy

Gabbard, Hunter *et al.* arXiv:1909.06296

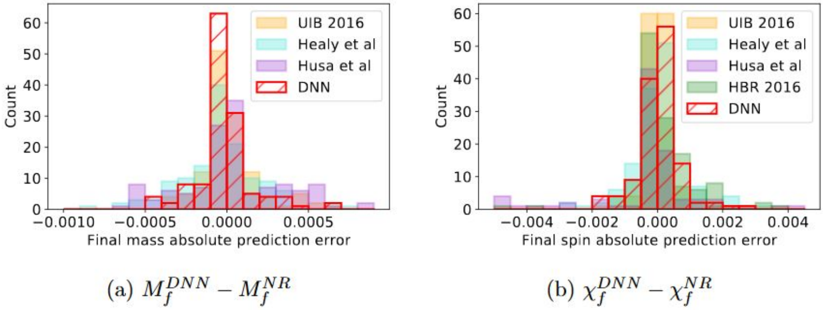
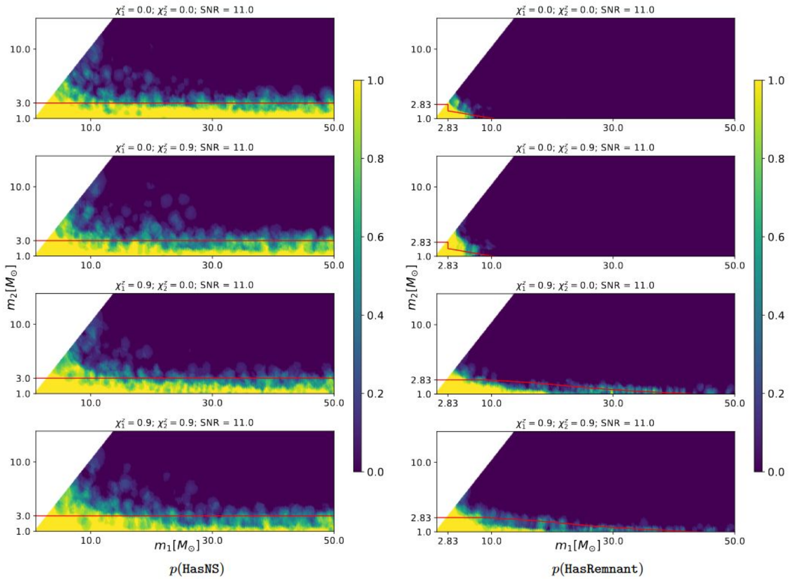


Figure 2: Residual error on the remnant mass $M_f(\eta, S_{eff}, \Delta\chi)$ (a) and spin $\chi_f(\eta, S_{eff}, \Delta\chi)$ (b) as predicted by the DNN for the non-precessing BBHs. Our error is compared with the fits performed by the UIB group in 2016 [6], Healy et al [34], Husa et al [12] and Hofmann, Barausse and Rezzolla (HBR) [13].

Predicting the properties of black holes merger remnants with Deep Neural Networks

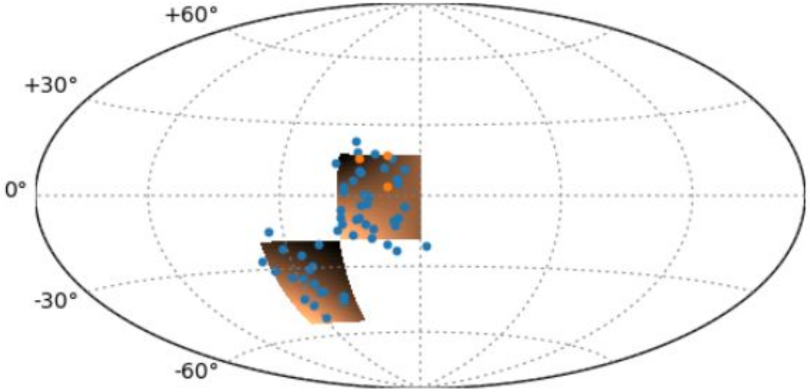
Leïla Haegel, Sascha Husa, arXiv:1911.01496

GW signal sky localization



A Machine Learning Based Source Property Inference for Compact Binary Mergers

Deep Chatterjee, et al arXiv:1911.00116

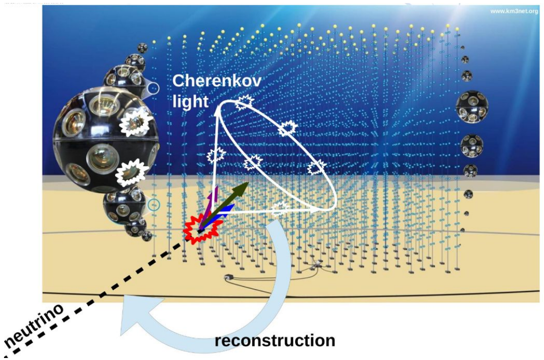


Using Deep Learning to Localize Gravitational Wave Sources

Chayan Chatterjee, Linqing Wen, Kevin Vinsen, Manoj Kovalam, Amitava Datta
arXiv:1909.06367

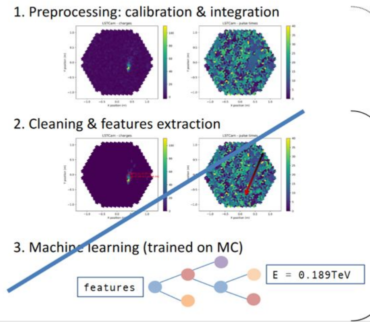
Machine Learning in ESCAPE partners

KM3NeT-ORCA/ARCA



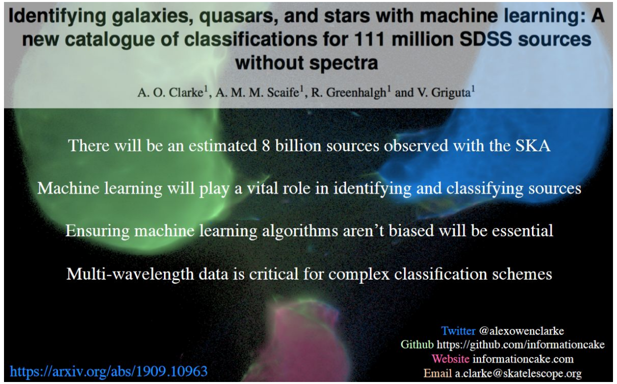
planned orca detector:

- 3D instrumented volume
- Particles leave light signature
- → Like a 3d camera
- → Use image recognition networks



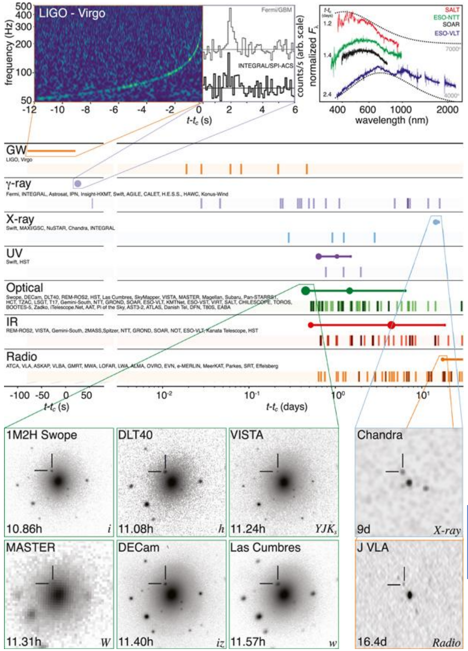
Cherenkov Telescope Array

GammaLearn: Deep Learning applied to the **CTA data**



Square Kilometre Array (SKA)

Multimessenger Astronomy and Gravitational Wave Transient signals



The Astrophysical Journal Letters, Volume 848, Number 2

EM: supernovae emission, long GRB

- Known waveform
  - Transient signal

Compact binary coalescence (CBC)

- Unknown waveform
  - Transient signal

Core Collapse Supernovae (CCSN)

- Known waveform
  - Persistent signal

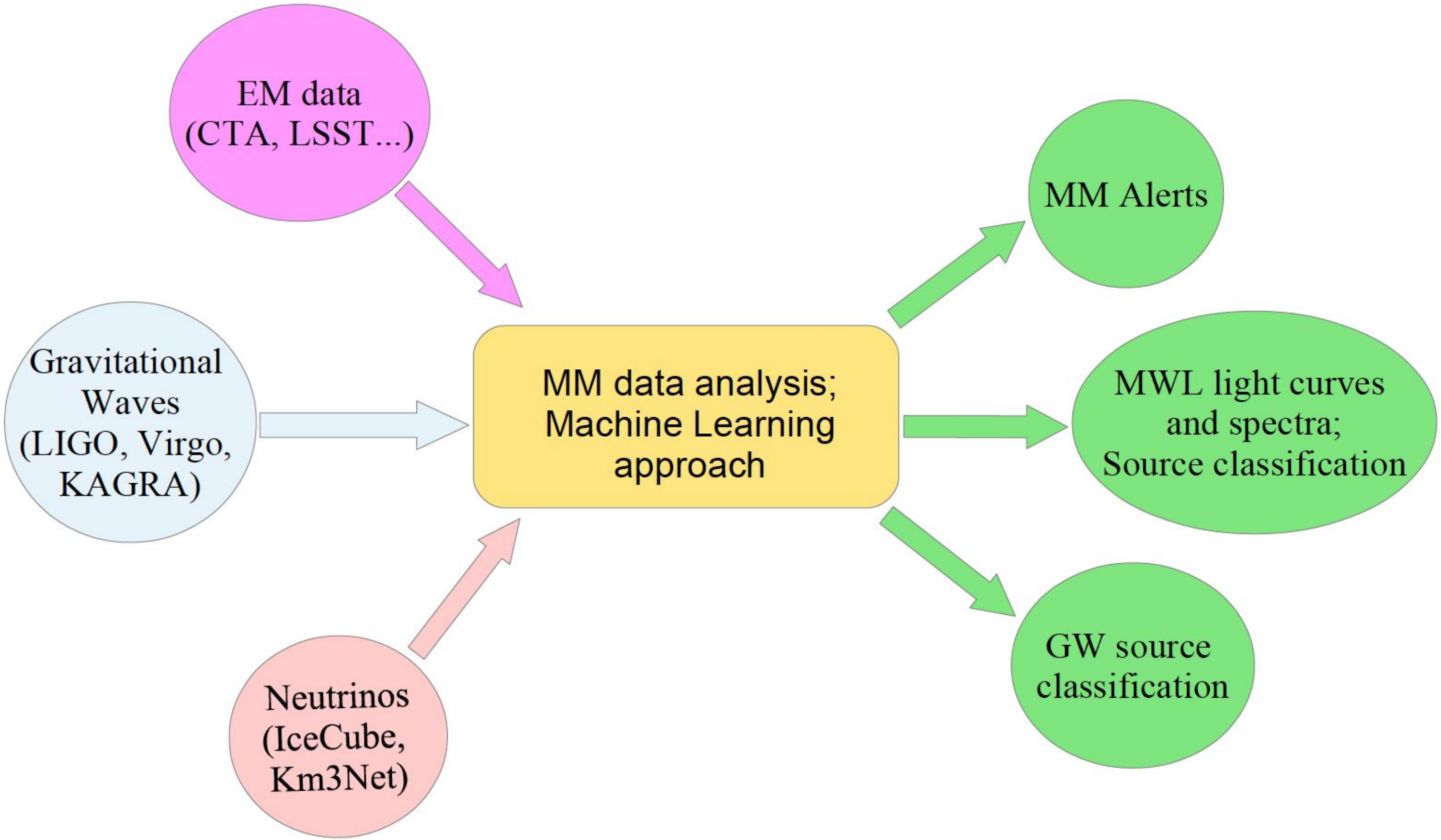
Continuous Waves (CW)

EM: short GRB, kilonova

known odel
- Persistent signal

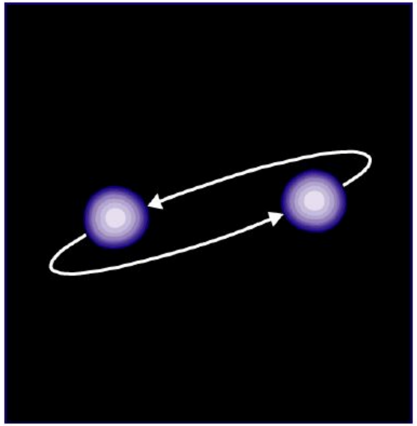
Stochastic Background (SB

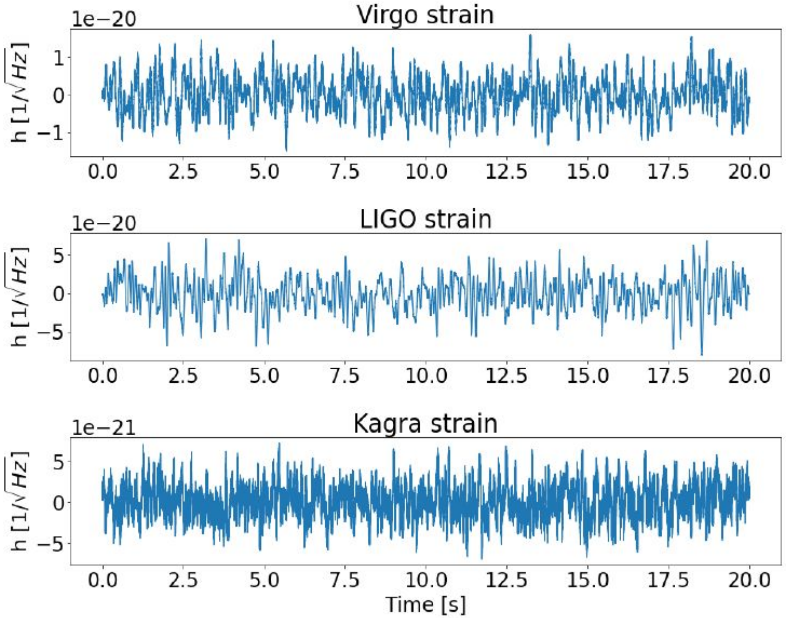
Multi messenger approach

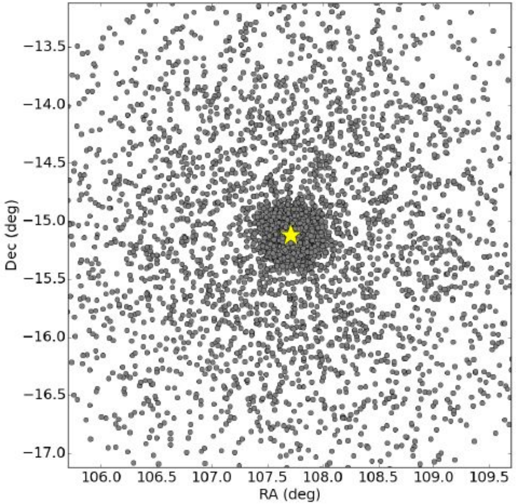


B. Patricelli courtesy

Multi messenger approach: simulating CBC+GRB events







B. Patricelli et al 2018

See B. Patricelli’s talk

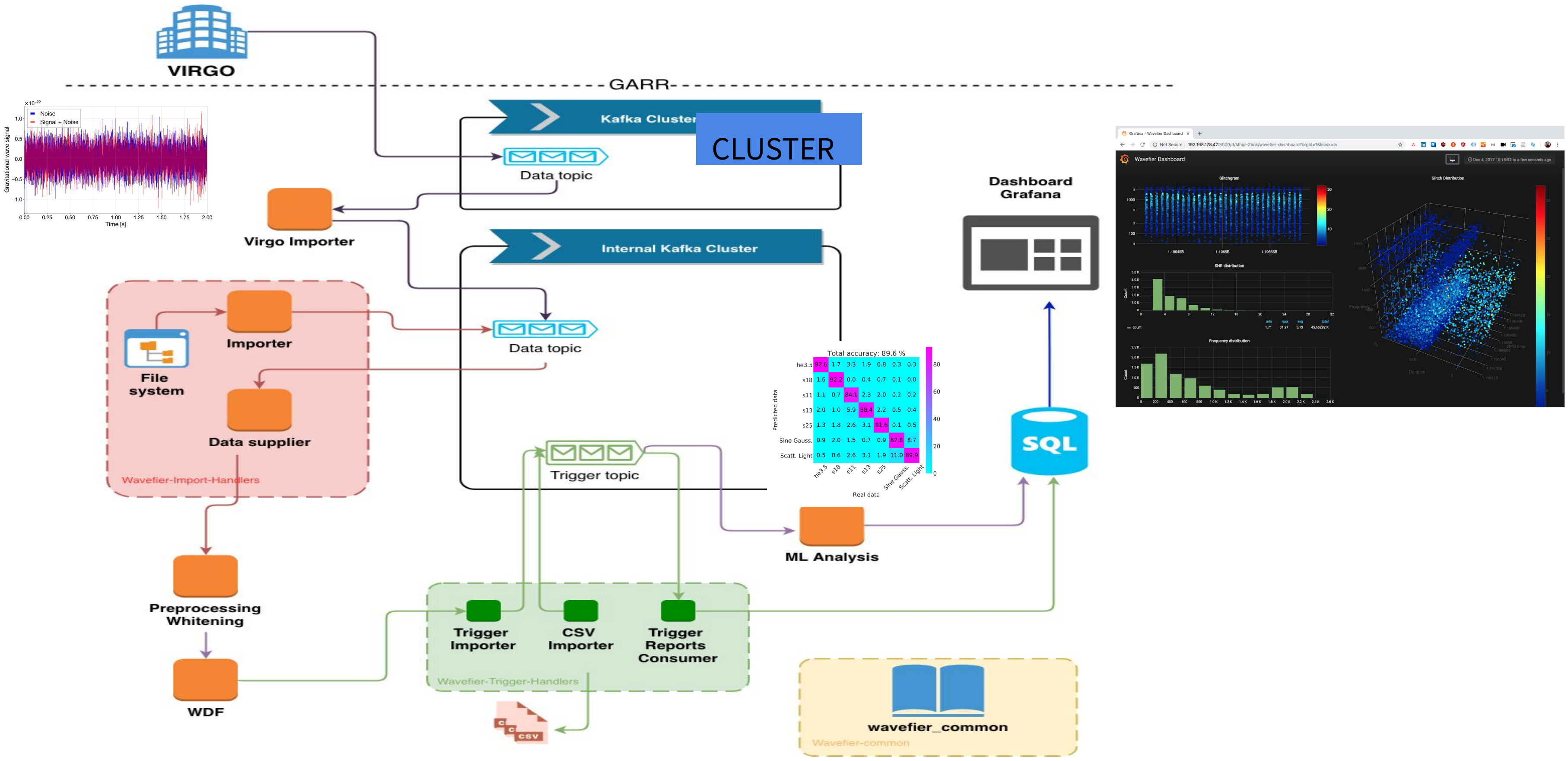
A prototype for Real time analysis: Wavefier

Real time Gravitational Wave transient signal classifier

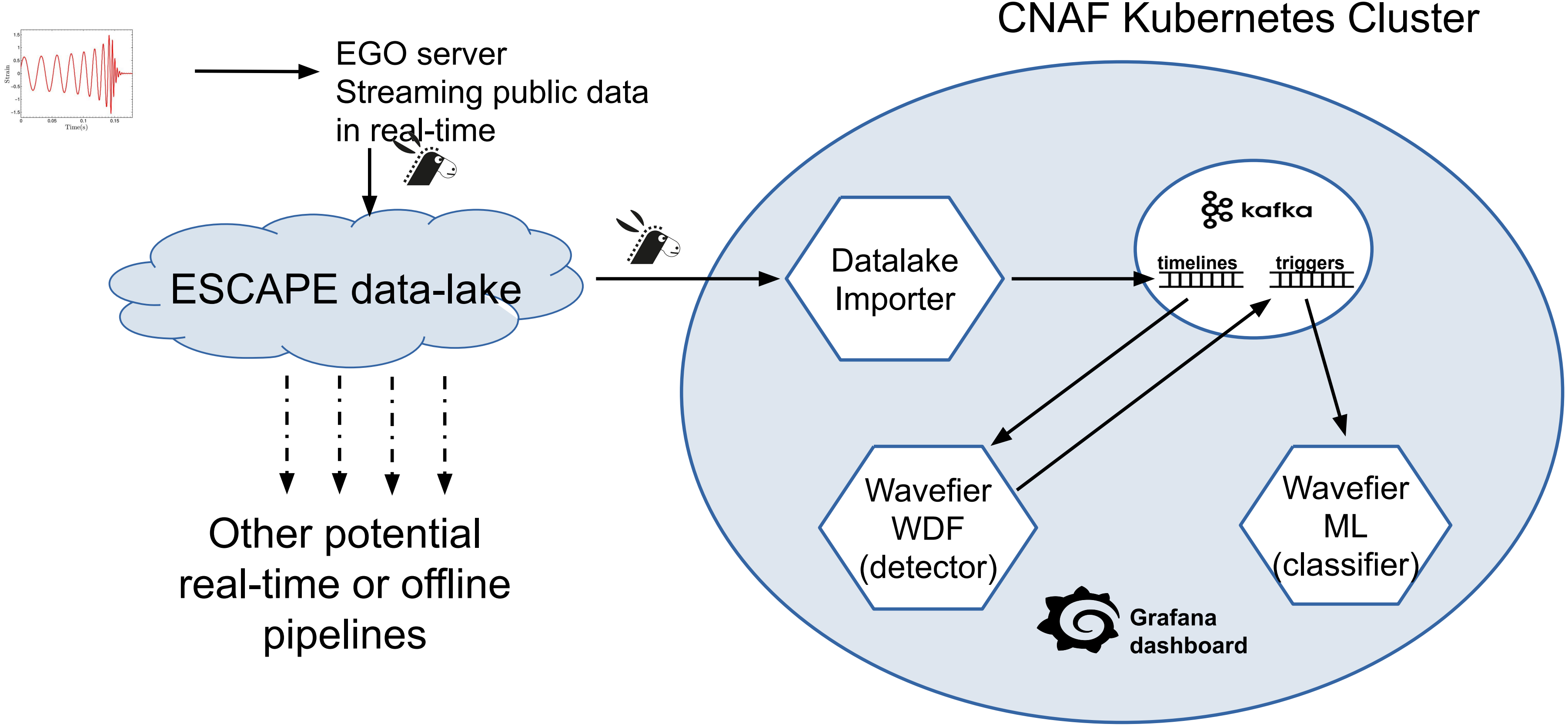
Key Objectives

- Setup a prototype for a **real time** pipeline for the detection of transient signals and their **automatic** classification
- Test different software architecture solutions to prototype a **scalable** pipeline for **big data** analysis in GW context.
- **Interoperability** and access to data and services
- **ICT services** supporting research infrastructures
- Use of **data in network** infrastructures and services

Wavefier/online Architecture

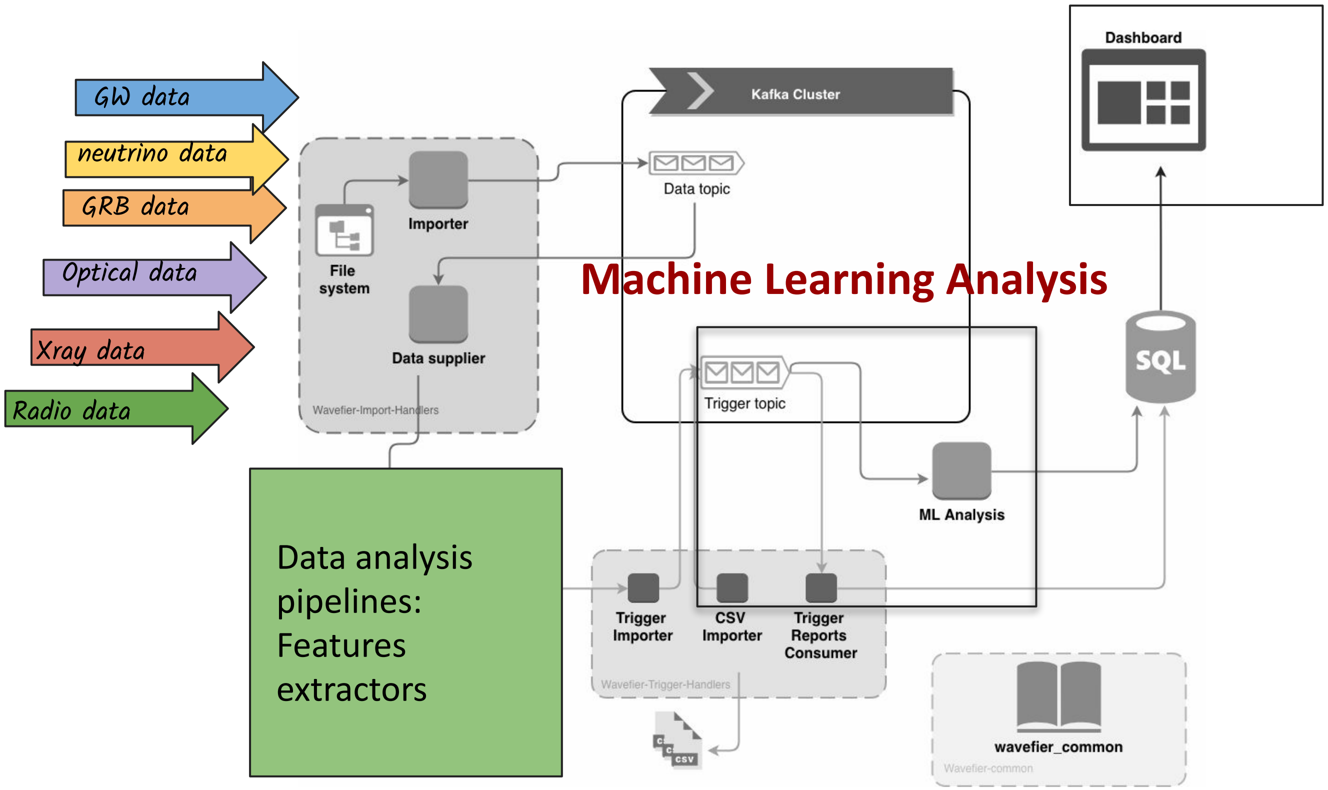


Wavefier in ESCAPE framework



P. Chanial courtesy

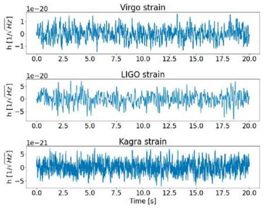
MMA in ESCAPE framework

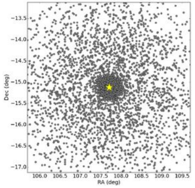


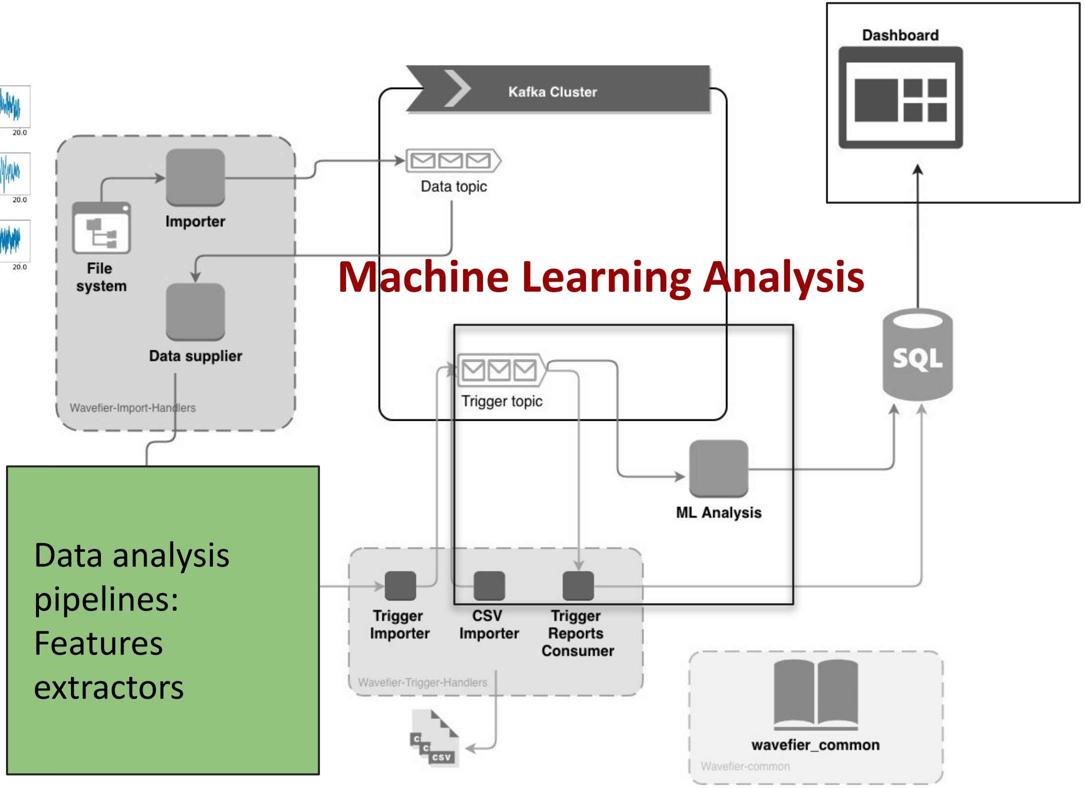
Results

Team
E. Cuoco
B. Patricelli
A. Iess
F. Morawski
P. Chanial
S. Vallero
& **Trust-IT team**

GW-GRB analysis in ESCAPE framework







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Science Project in EOSC Future

ESCAPE will participate with 2 Test Science Project:

- Dark Matter
- **Extreme Universe and Gravitational Waves**

Extreme Universe

➔ Exploit Astrophysical extreme phenomena through the gravitational waves, GRB, FRB, neutrino messengers.

➔ Understand extreme matter and particle processes in strongly curved space-time and compact objects

➔ High Energy astrophysics

EOSC Future under H2020 programme in order to integrate, consolidate, and connect e-infrastructures, research communities, and initiatives in European Open Science Cloud (EOSC).

Thank you for your attention

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EGO - Virgo

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