NEWS

NEw WindowS on the universe and technological advancements from trilateral EU-US-Japan collaboration

Overview of WP2 “Gravitational Wave Physics”

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Web site: risenews.df.unipi.it

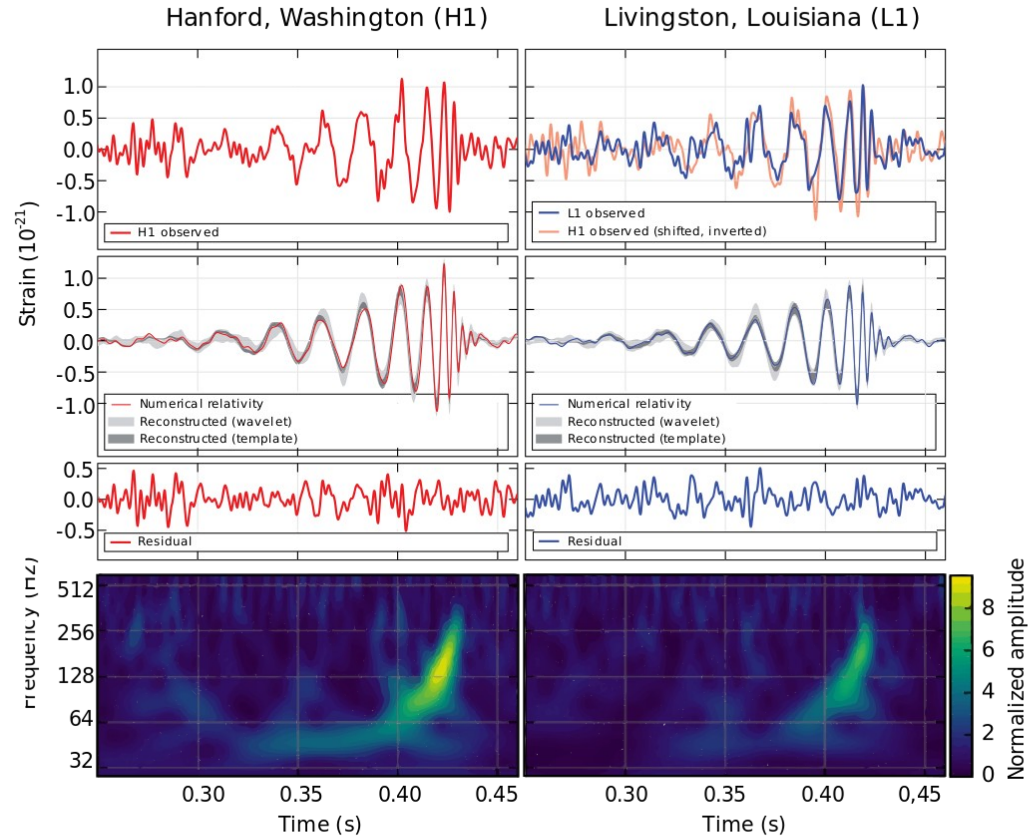
European Commission

The discovery of Gravitational waves

- Gravitational waves are ripples in spacetime traveling at the speed of light
- First event discovered on Sep. 2015, 100 after Einstein's General Relativity

Event GW150914
(coalescence of binary
black hole)

Abbott et al 2016, PRL



PRL 116, 061102 (2016) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 Hz with a peak gravitational-wave strain of 1.0×10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{+160}_{-180} Mpc corresponding to a redshift $z = 0.09^{+0.03}_{-0.04}$. In the source frame, the initial black hole masses are $36^{+5}_{-4} M_\odot$ and $29^{+4}_{-4} M_\odot$, and the final black hole mass is $62^{+4}_{-4} M_\odot$, with $3.0^{+0.5}_{-0.5} M_\odot c^2$ radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

DOI: 10.1103/PhysRevLett.116.061102

I. INTRODUCTION

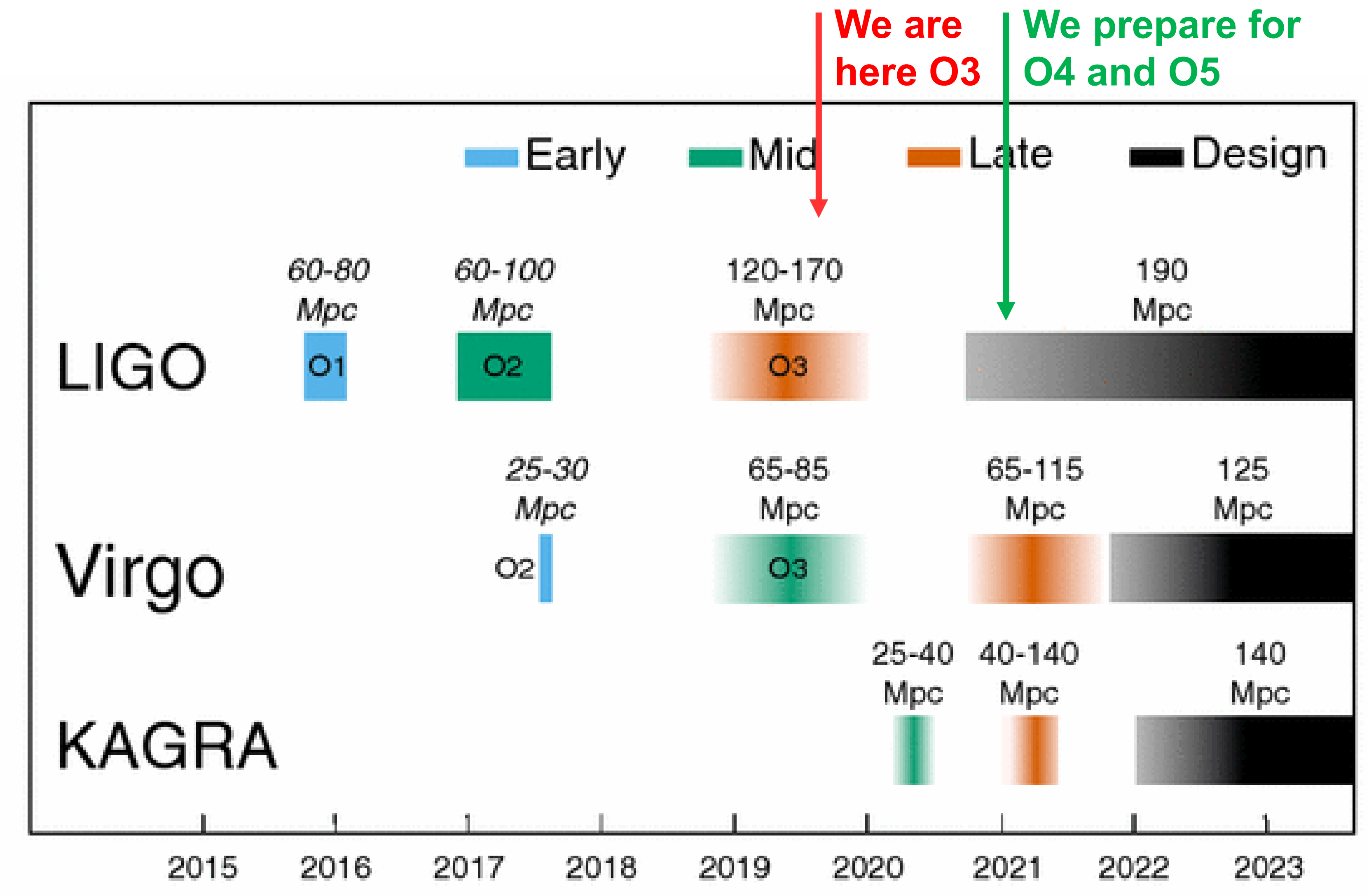
In 1916, the year after the final formulation of the field equations of general relativity, Albert Einstein predicted the existence of gravitational waves. He found that

The discovery of the binary pulsar system PSR B1913+16 by Hulse and Taylor [20] and subsequent observations of its energy loss by Taylor and Weisberg [21] demonstrated the existence of gravitational waves. This discovery,

LIGO and Virgo running Observational Run "O3"

O3 is 1-year long observing run. Commissioning break in Oct 2019, restart and end in April '20

- Abbott et al. 2018 "Observing scenario" paper, LRR

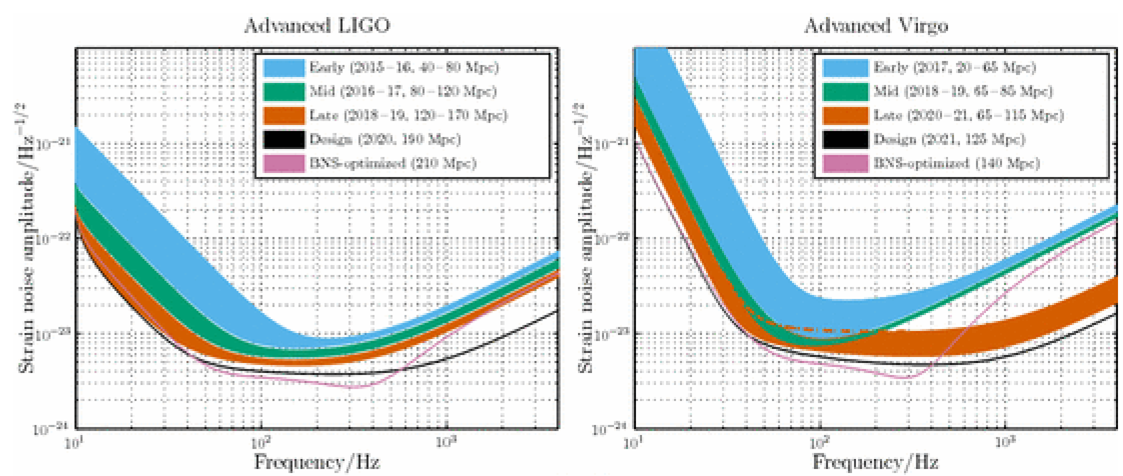


Improving sensitivity during O3

- Abbott et al. 2018 “Observing scenario” paper, LRR

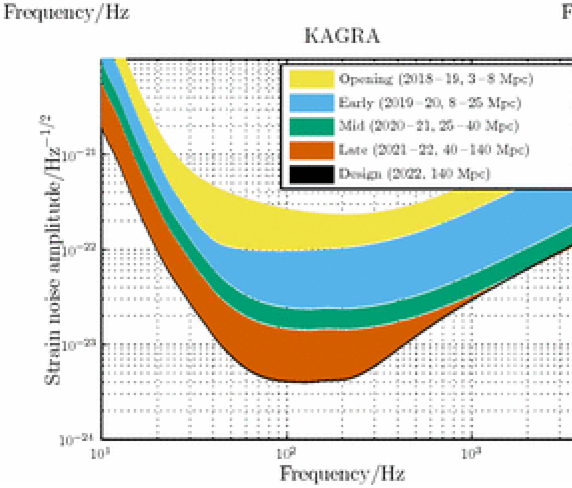
Significant upgrade to increase sensitivitity by 10x
Wrt “previous generation” LIGO and Virgo (2010s’)

This means 10x distance reach
→ 10^3x larger volume
→ 10^3 number of events



Extremely tiny signals
Arm deformation ~10^{-18} m

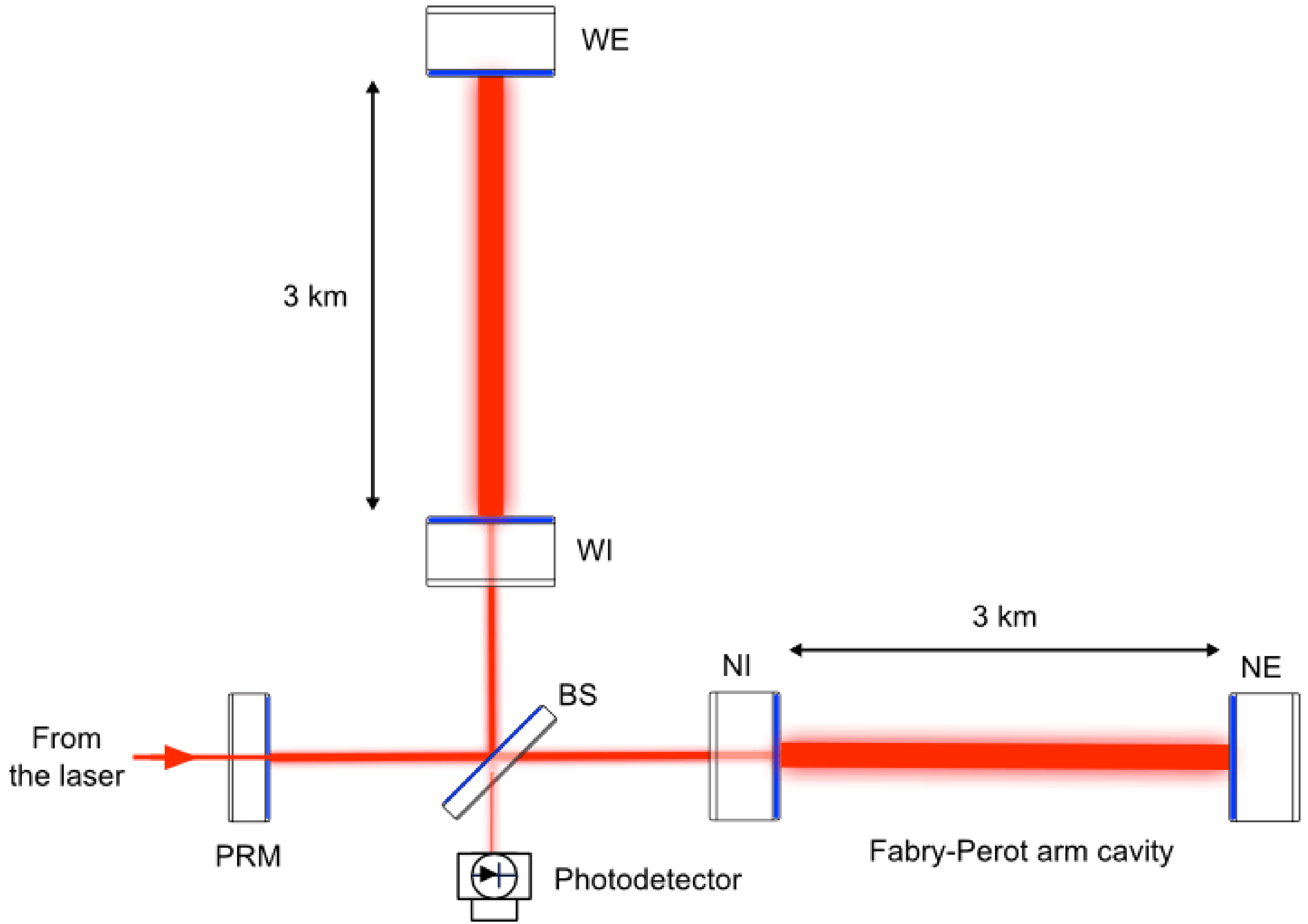
During O3 increase in sensitivity (e.g. larger laser power)



The Virgo detector

- Virgo is a 3-km laser interferometer located in Cascina, Pisa
- It's the largest European detector, and with LIGO forms an international network→ Increase localization of GW signals
- Typical GW signals produce a deformation
of the order of 10^{-18} m
- Removing the background noise sources
is key to detection
- Observations started in 2017

The Virgo detector



Simplified scheme of Virgo optical layout

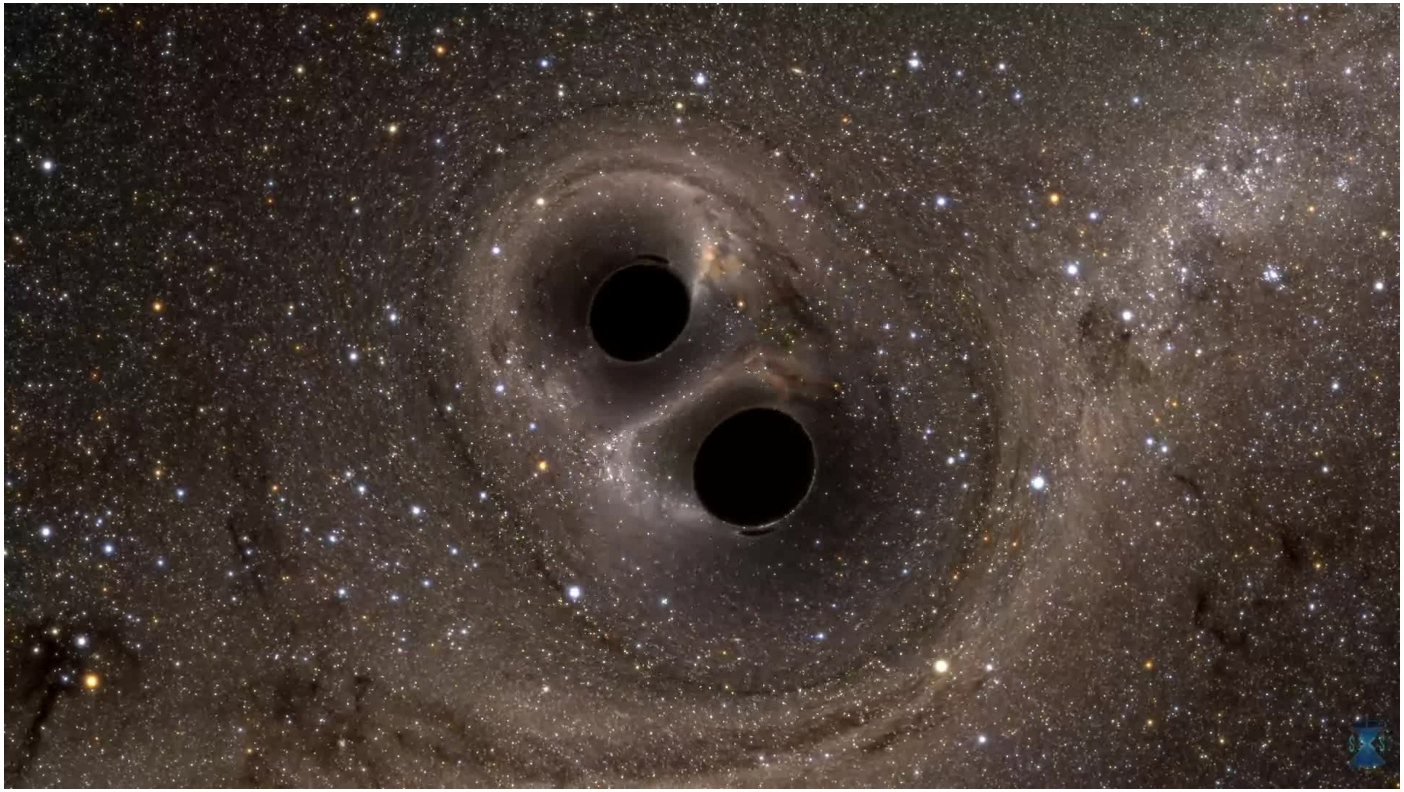
See more details on WP3's talk

The Virgo detector

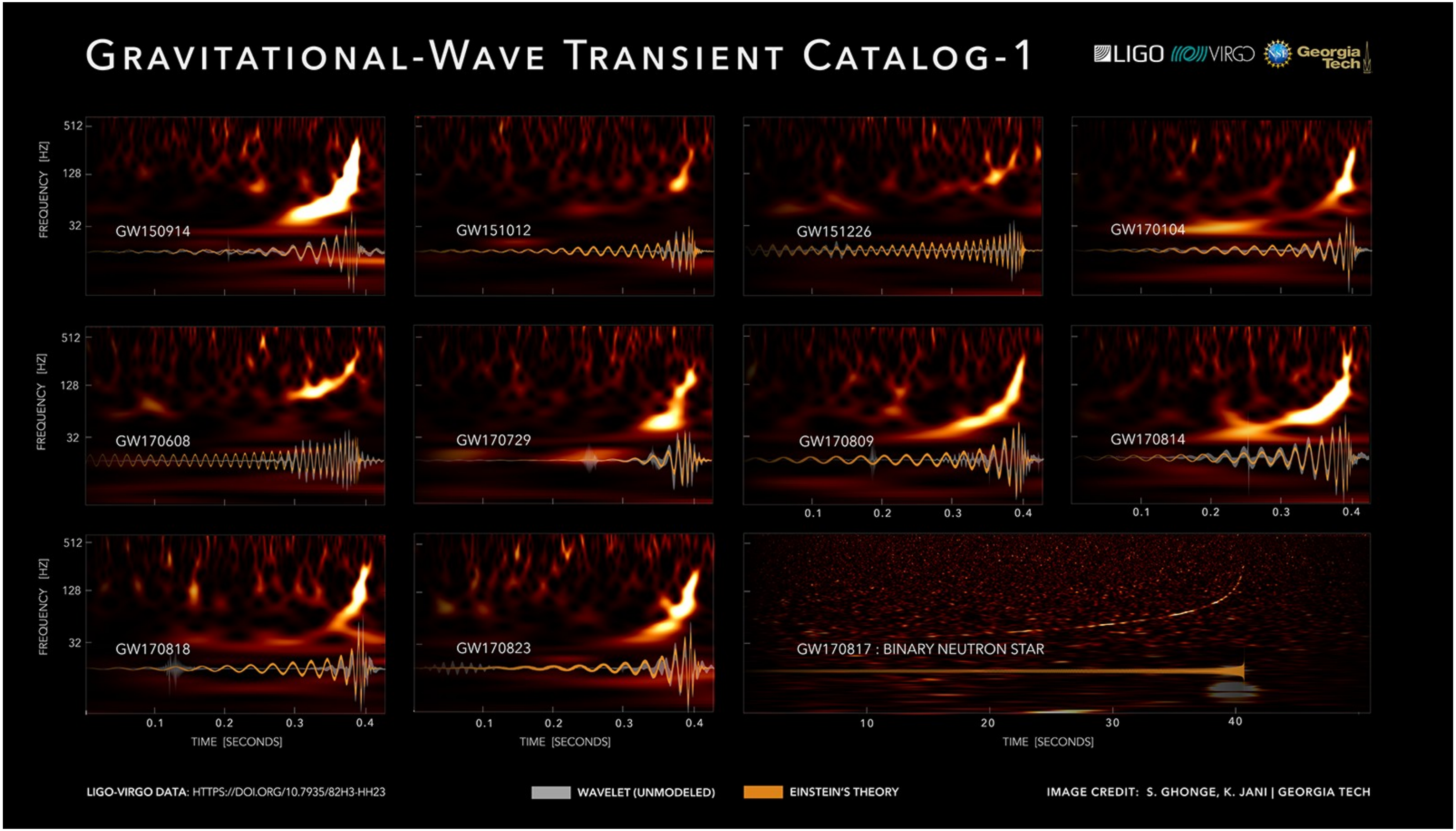
Why Gravitational Wave Physics?

- Gravitational waves will open a new window on the Universe
  - Probing “dark” astrophysical sources (e.g. black holes)
  - Study black hole physics
- Test general relativity against other theories on gravitation
- Build an independent distance scale ladder
- Investigate Big Bang cosmology (primordial GWs)

- GW carry complementary information with respect of light
  - → multimessenger astrophysics!



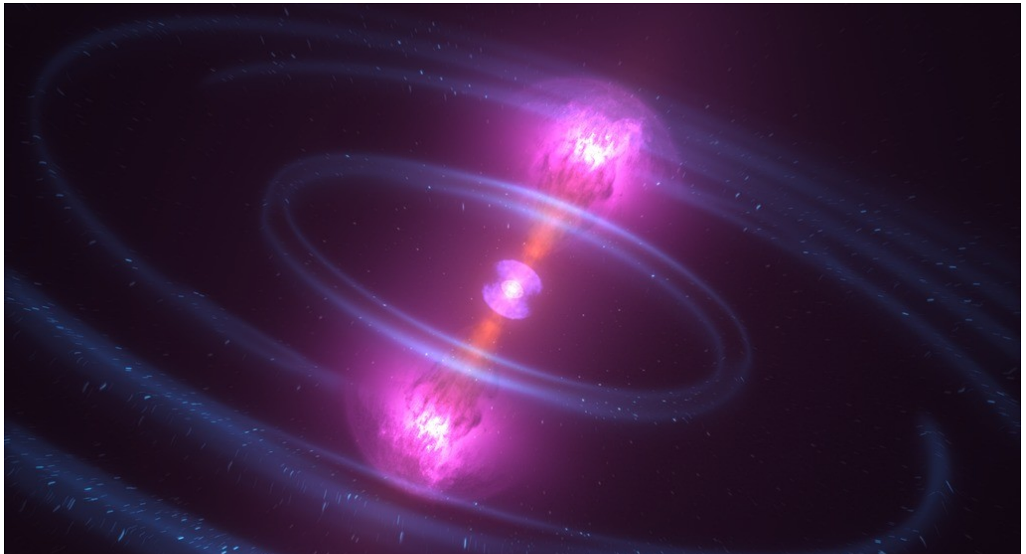
Why Gravitational Wave Physics?



First GW catalog
Abbott et al 2019, in press (arXiv:1811.12907)

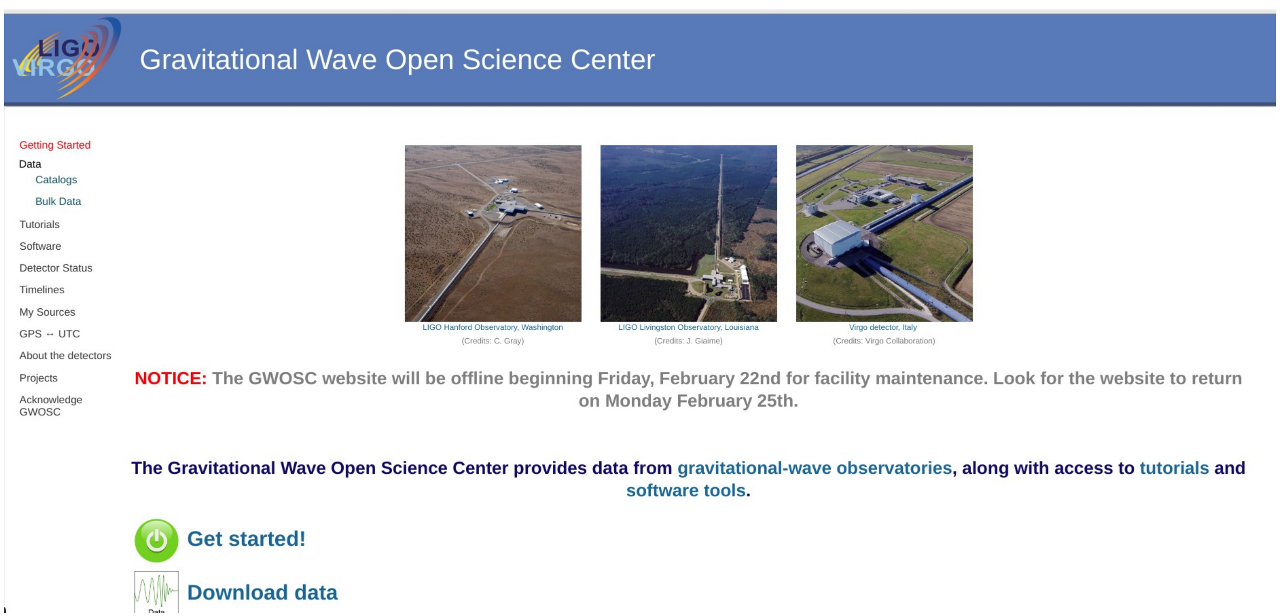
Virgo and multimessenger science

- Combining GW and light emission is an unique probe to astrophysical sources and to fundamental physics
- Event of August 17, 2017
  - First GW detection from merger of 2 neutron stars
  - Virgo crucial for the localization of the event, to allow for EM follow-up
  - First counterpart detection at gamma rays, X, optical, etc
  - Milestone in multimessenger science
- Open Public Alerts
  - More NS-NS and NS-BH canditate events, analysis in progress



Goals of the WP2

- The WP2 has 4 main goals
  - Develop GW data analsys to extract physics from GW events;
  - Support multimessenger science with GW and EM radiation (quick alerts from LIGO-Virgo to the worldwide community);
  - Contribute to the definition of 3rd generation GW detectors, in particular the Einstein Telescope project;
  - Support digital preservation of gravitational wave data, also in the form of public data;



The LIGO-Virgo open center, whose recent upgrade strongly benefitted from NEWS secondments

www.gw-openscience.org

Objectives of WP2

- O2.1: Establish a network for searches of electromagnetic counterparts to Gravitational Waves
  - Study GW/EM scenarios, in particular with high-energy photons
  - Visions on KAGRA+ (Collaboration with Kagra+ design board)
- O2.2: Reduce the localization latency for gravitational wave events with electromagnetic counterparts
  - Develop machine learning code for data quality
- O2.3: Develop a collaboration network for third generation detectors:
  - Explore and develop science cases for 3G
    - non-GR polarization in GR formalism
- O2.4: Collaborate with LIGO on digital preservation of gravitational wave data:
  - Updated to LIGO Open Science Center (LOSC) to Gravitational Wave Open Data Center (GWOSC), including Virgo
  - Public release of O1 GW data
  - Public release of First GW transient Catalog (GWTC-1)
  - Public release of O2

WP3 - Status and plans

A remark: WP2, the physics accessed through the detectors is interlaced with WP3 (Detector Hardware). Several secondments are strongly connected

Main activities so far

- Data analysis to improve detector characterization with innovative algorithm, to improve the localization of GW events and the production of alerts.
- Development of common roadmap for 3G detectors and for collaboration with KAGRA 🔔WP3.
- Upgrade LIGO open data center, now including Virgo under a common name and web portal
- Towards O4: O3 common-tool framework for front-end data analysis with 4 detectors (secondments started).
- Continuous Wave detection (CW): undetected sources so far, exploiting and extending methods (secondments started)
- New data in O3, thus requiring traveling to work on data analysis, increasing secondments (from the spring ‘20).
- Developed new collaborations on data analysis, but also HW developments towards 3G 🔔WP3, involving new partners (e.g. Univ of Missouri, MIT, Hong Kong University)
- Opening collaborative framework with Japan for stochastic GW detection

Work Package 1 – Deliverables

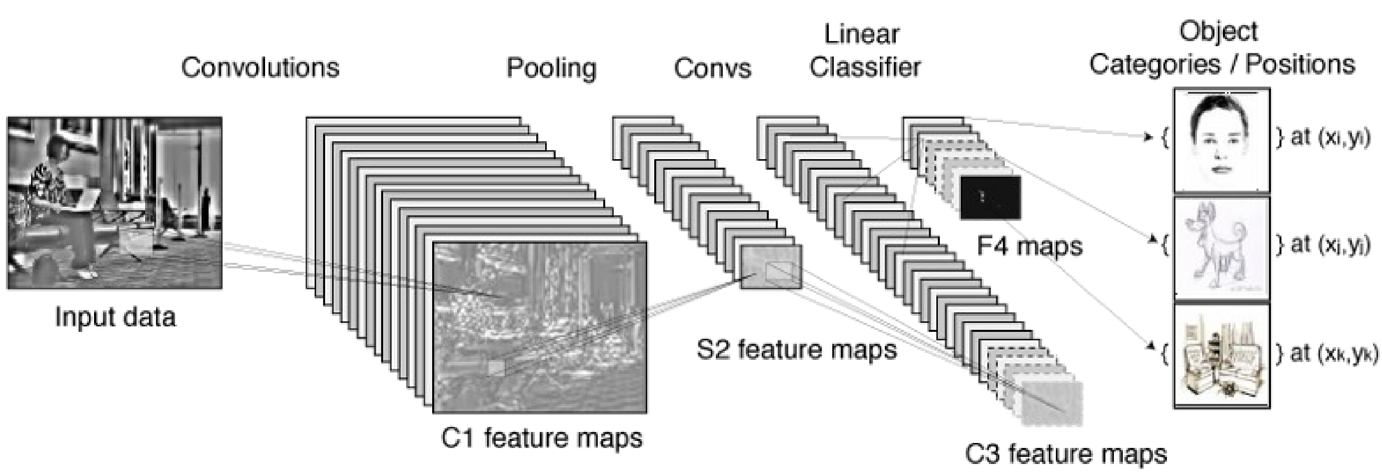
The deliverables are relative to

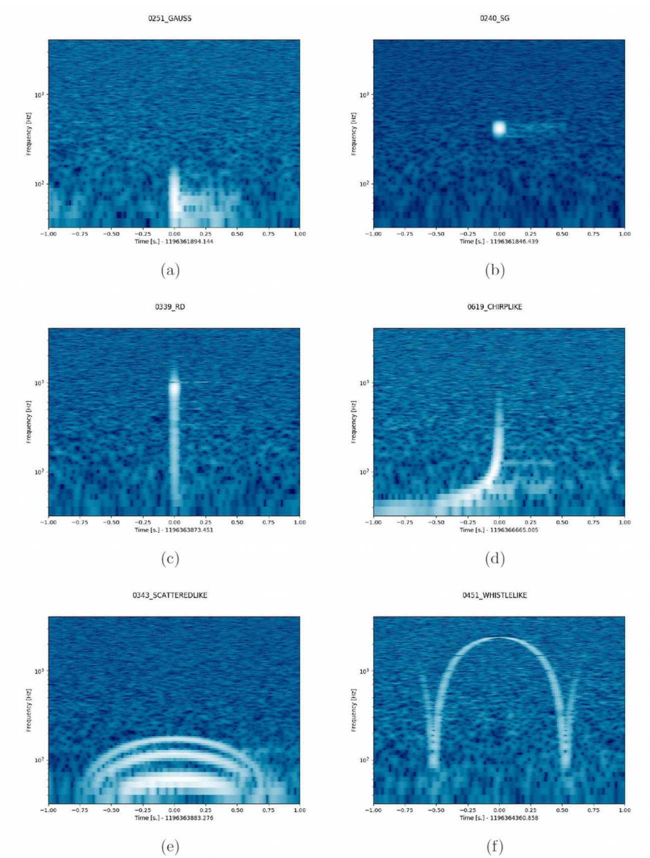
- Extracting maximum physics information from the gravitational wave (GW) events
- Pursuing an electromagnetic follow up in a multimessenger approach
- Defining the evolution of future GW detectors

- D2.1 : Roadmap for third generation detectors [36 months]
  - Collaboration on Suspensions and Seismic isolation systems with LIGO & KAGRA
  - Collaboration with KAGRA+ design board
  - Develop and sharpen 3G science case
- D2.2 : Gravitational Wave Event Localization Code [24]
  - Noise characterization and removal essential to provide real triggers for GW events for the electromagnetic follow-up
  - Developed a machine learning pipeline to characterize transient glitch noise, ready for O3 (Razzano&Cuoco, 201, CQG)
  - Started a new collaboration with University of Missouri (new Partner), to study the impact of rapid, online noise removal on the localization
  - Started collaboration with MIT on 2G/3G data analysis (CBC and Testing GR, high-accuracy parameter estimation)

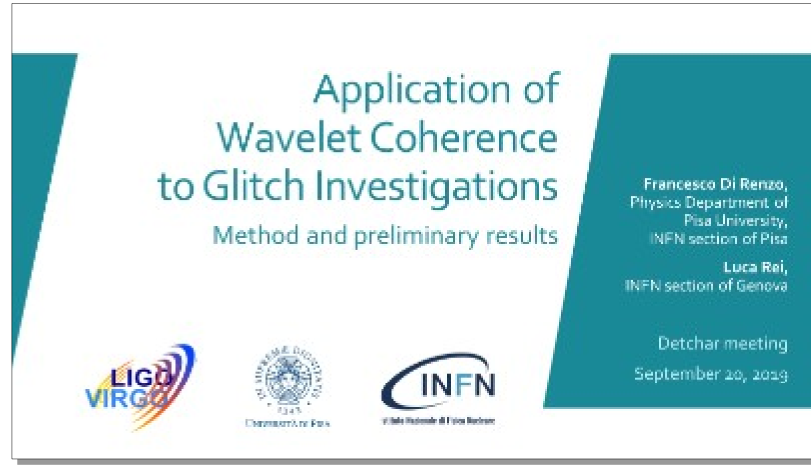
Low-latency detector characterization

- Detector characterization is important for low-latency detection and localization
- Transient noise events (glitches) can impact data quality and mimic real astrophysical signals (see Jess McIver's talk)
- Detect and classify glitches is one of the most important tasks for detector characterization and data analysis (e.g. low-latency & detector optimization)
- Automatic pipeline based on CNN (e.g. Powell+15, CQG,32,215021, Mukund+17,PRD,95,104059)
- Quick tests for correlations and importance of auxiliary channels (with Uni Missouri)

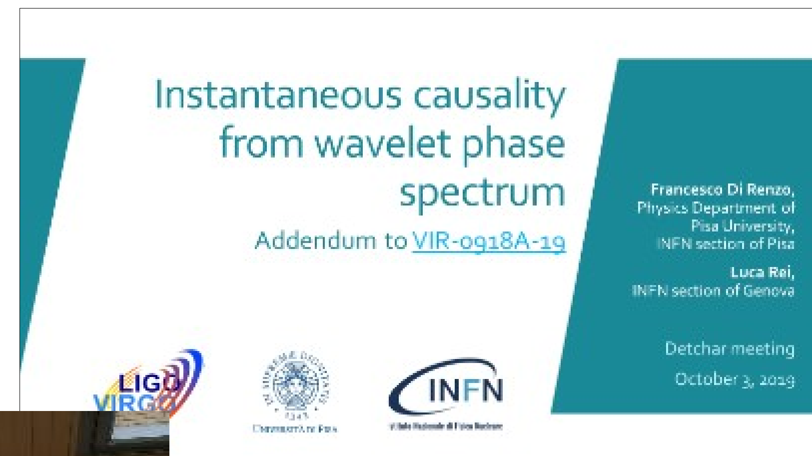


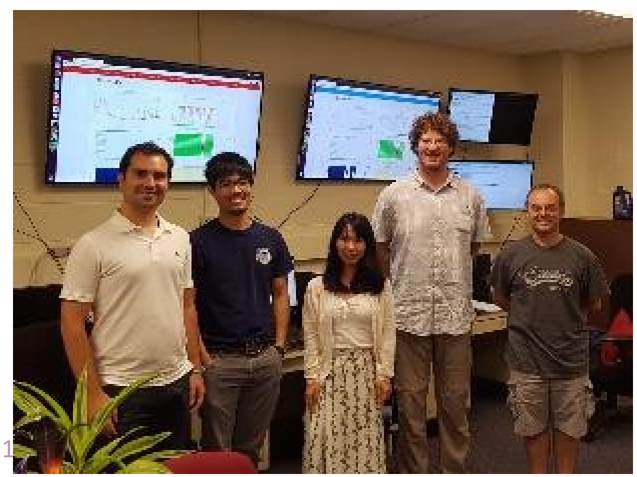


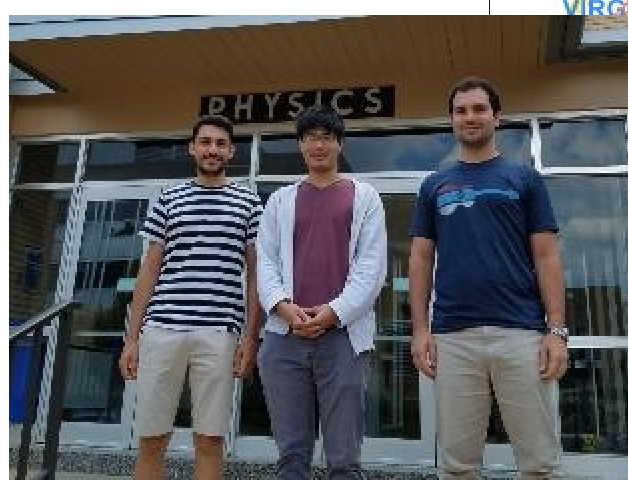
Secondments on detchar on Caltech e Missouri



In Lake Geneva, I met Prof. Cavaglia', who was interested in my research on noise non-stationarities and the study of detector glitches.
Thanks to RISE NEWS I had the chance to visit him and his research group at Missouri University of Science & Technology.







From F. Di Renzo's talk

Open data release

- From LIGO Open Science Center (LOSC) to Gravitational Wave Open Science Center (GWOSC)
  - Extended upgrade of the background Python web engine
  - New material upgrade
  - Virgo contribution integrated in the portal

- Final checks and implementation at Caltech in July 18, updates in Jan 2019
- Web portal has been tested and now is online (https://www.gw-openscience.org)
- New interface to host catalogs and new events
- Full strain data for O1 and O2 released

Example of Work Package 2 output
The GW open data portal

O2 public release on Feb 27

RISE secondments in 2018/2019 crucial to establish a new collaboration between LIGO and Virgo teams in order to push forward and deploy the first new, network-based, GW open data center

https://www.gw-openscience.org

NEWS Project

(D. Laghi)

- **Research group**: TAPIR at Caltech
- **Research project**: search for an accurate method to measure the orbital eccentricity in Numerical Relativity (NR) waveform models from binary black hole (BBH) simulations
  - **Project summary**: improvement in the accuracy and stability of the procedure currently adopted for measuring the orbital eccentricity in NR BBH simulations [Buonanno et al., PRD **83**, 104034 (2011)] through a minimization of the waveform mismatch with an eccentric Post-Newtonian code

- **Planned duration**: 3-6 months (on-site from Jan-Feb ’20)

Work Package 2 – Secondment plans

- Secondments have been focused on establishing collaborations for 3G and to bring Virgo, operative since 2017 in O2 run, to join the international network with LIGO
- Since Virgo commissioning is almost over and O3 is about to start, new data will be ready and a higher number of secondments focused on data analysis and 3G preparation

Secondments plan for 2019

Name	Period	Where	
W. Del Pozzo (UniPI)	3x10d in 2020	MIT	GW data analysis
F. Di Renzo (UniPI)	1m from Mar 18+1m in Jun-Jul	Caltech	GW data analysis & detchar
D. Laghi (UniPI)	1m in second half of 2019	Caltech	GW modeling for 2G/3G
A. Miller (INFN-RM1)	2x15d in the period Jul-Sept	ICRR	Machine Learning
G. Pagano (UniPI)	1m in early 2020	MIT	GW data analysis
E. Majorana (INFN-RM1)	2x15d in the period Jul-Sept	ICRR	GW Network 2G-3G
M. Razzano (UniPI)	2x15d in 2020	Caltech	Detchar & Data portal
O. J. Piccinni (INFN-RM1)	1 m in the period Aug-Dic	ICRR	Detchar