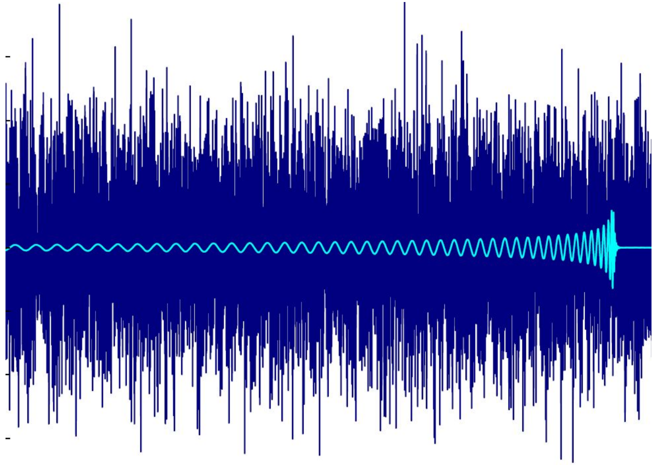
ICTS INTERNATIONAL CENTRE *for* THEORETICAL SCIENCES

TATA INSTITUTE OF FUNDAMENTAL RESEARCH

LSC LIGO Scientific Collaboration

Machine Learning in Gravitational-wave Astronomy



Prayush Kumar
ICTS-TIFR

25 May 2022

LABORATORY FOR INTERDISCIPLINARY BREAKTHROUGH SCIENCE, ICTS-TIFR

Gravitational-wave Astronomy

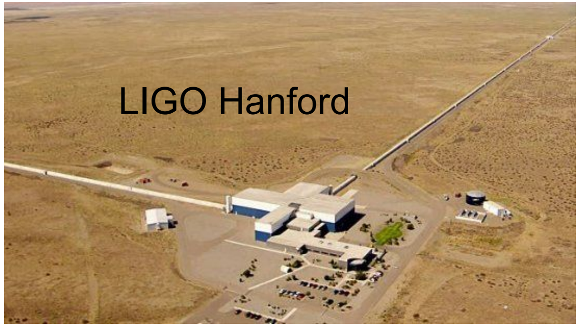
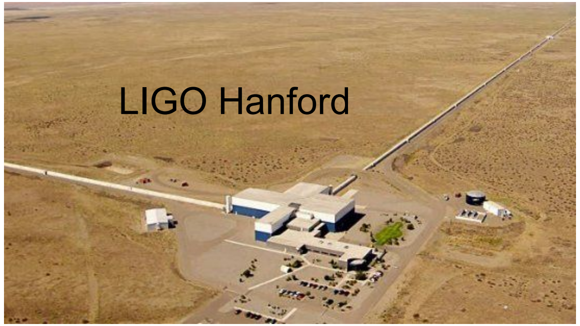
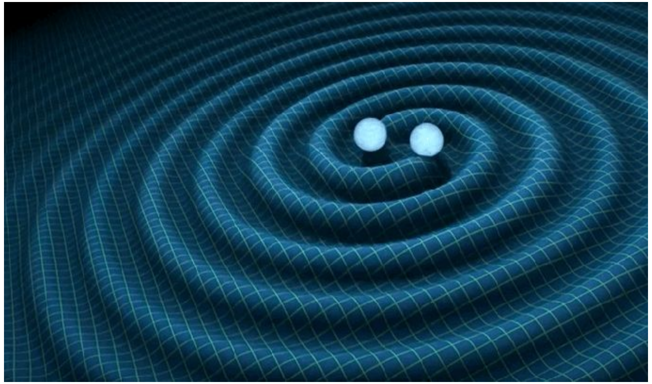
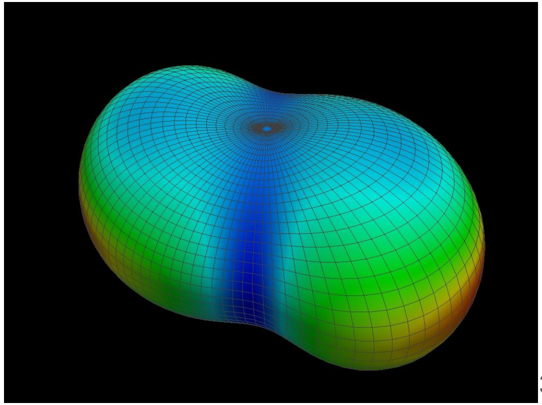


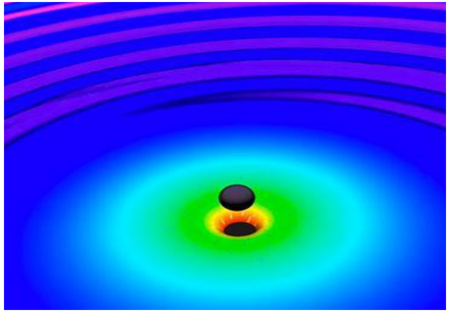
Image credit: Kavli Foundation, LSC;
https://cqgplus.files.wordpress.com;

Gravitational-wave Astronomy









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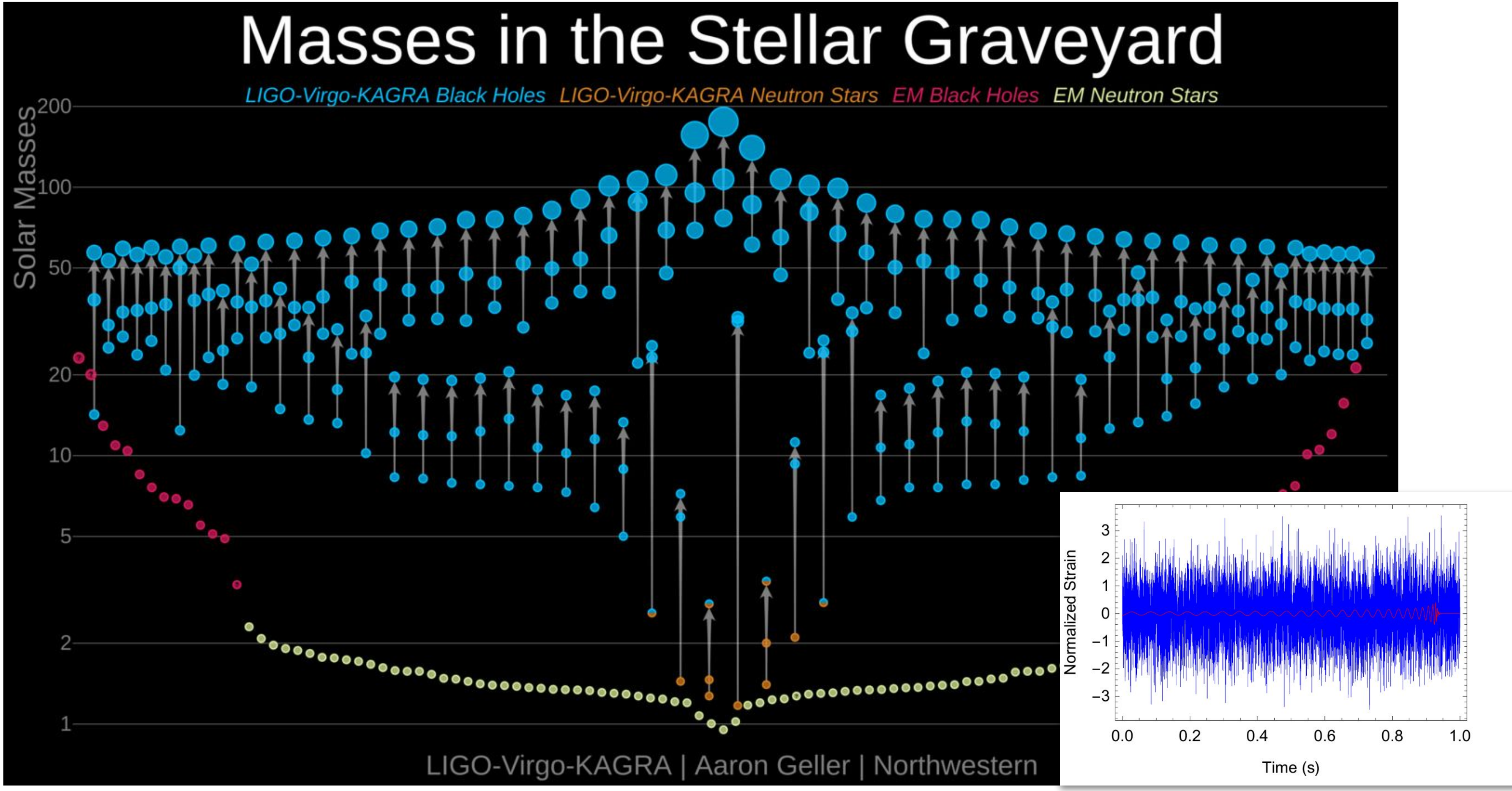
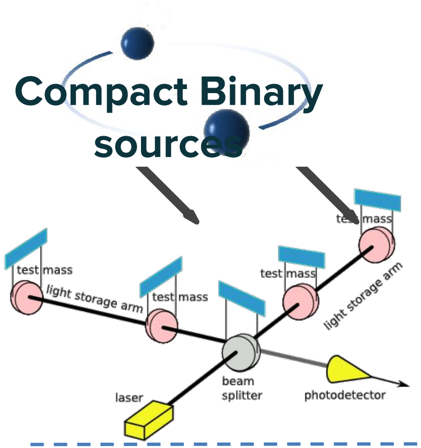
GW observations: nearly 100 and counting!



Anatomy of GW astronomy

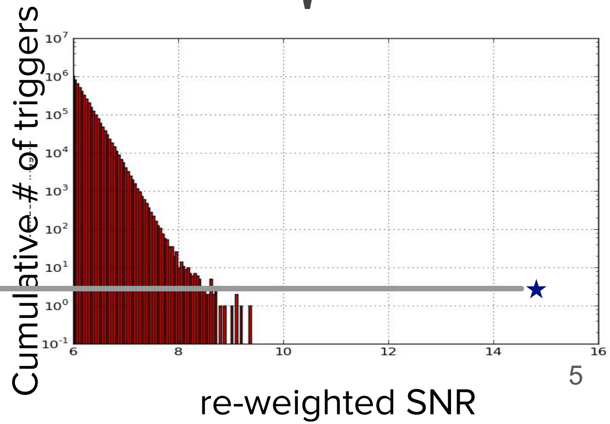


Calibration

GW
Strain Data

(Matched-Filtering based)

GW Detection Engine



Bayesian
Parameter estimation framework

Catalog of source masses, spins, location, intensity, ...

Astrophysical formation,
Population statistics,
Cosmological information,
Grav. Lensing,
Core-collapse SNe....

Anatomy of GW astronomy

GW
Strain Data

(Matched-Filtering based)

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Bayesian
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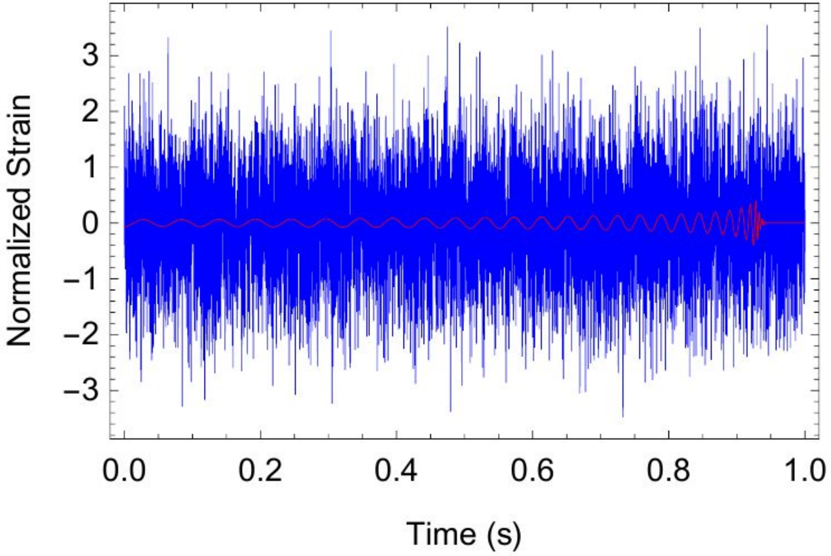
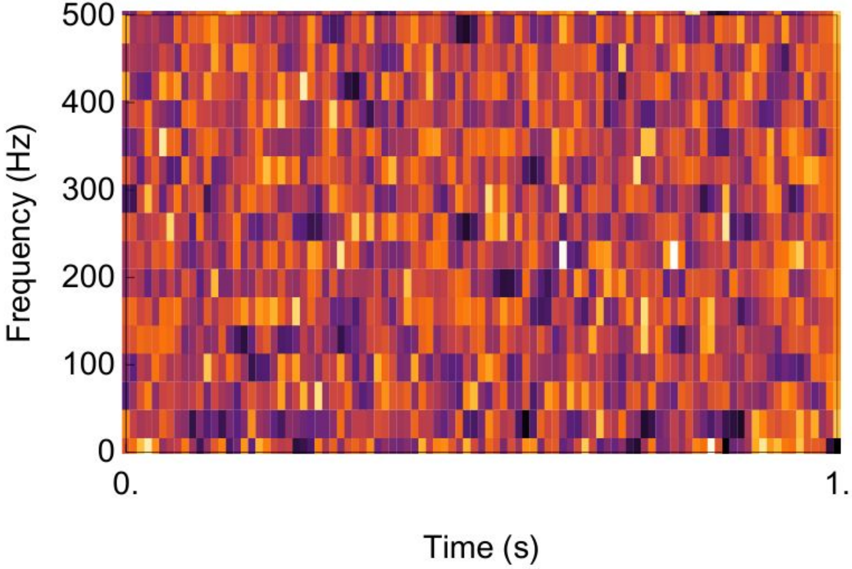
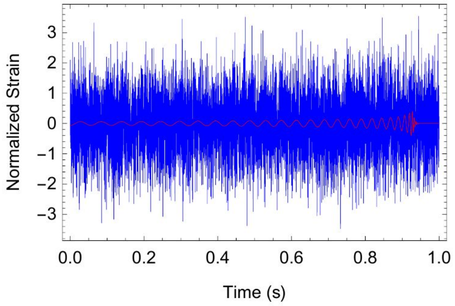
Catalog of source masses, spins, location, intensity, ...

1. Detection of GW signals

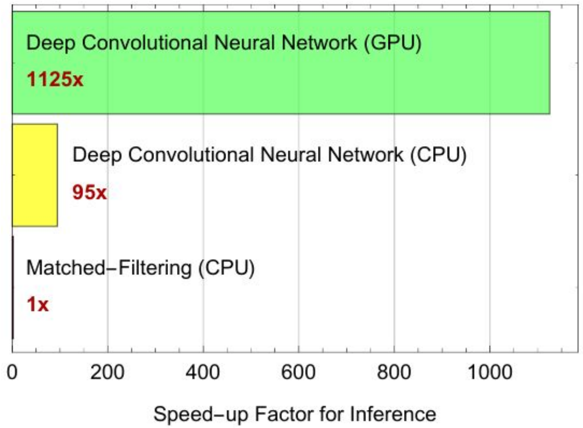


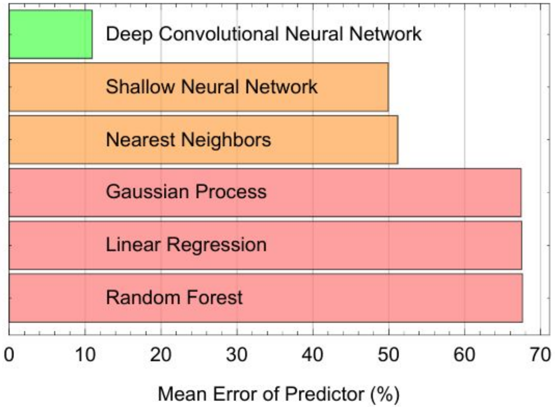


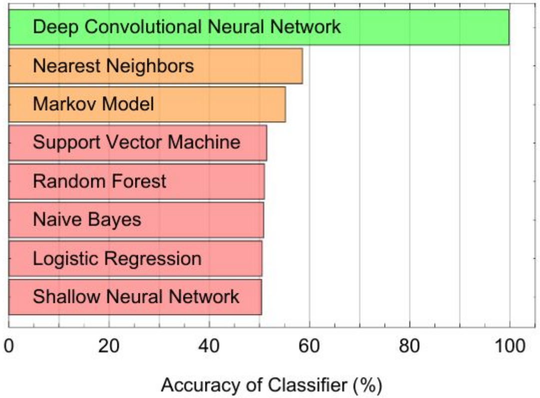
Detection of GW signals: George & Huerta (2016)



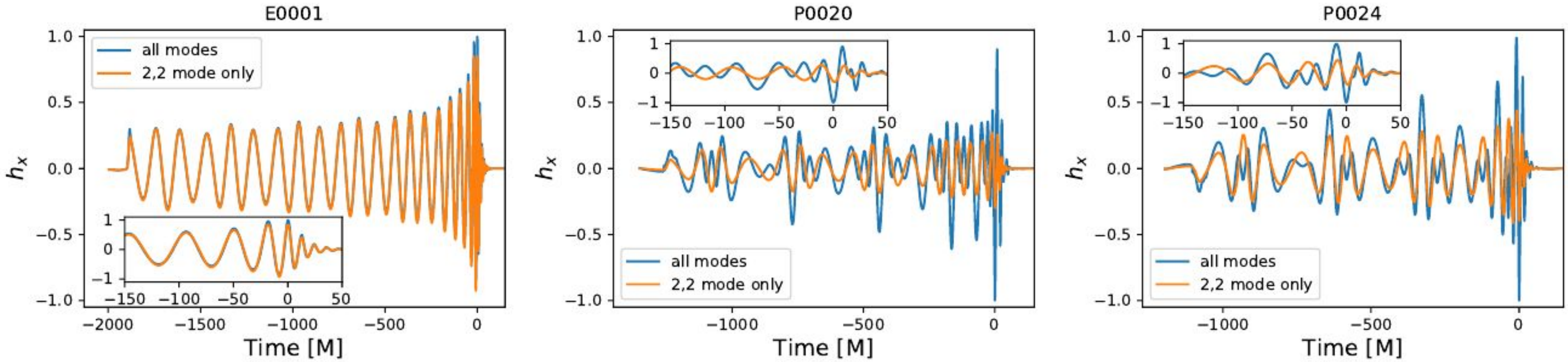
	Input	vector (size: 8192)
1	Reshape Layer	tensor (size: 1 × 1 × 8192)
2	Convolution Layer	tensor (size: 16 × 1 × 8177)
3	Pooling Layer	tensor (size: 16 × 1 × 2045)
4	Ramp	tensor (size: 16 × 1 × 2045)
5	Convolution Layer	tensor (size: 32 × 1 × 2017)
6	Pooling Layer	tensor (size: 32 × 1 × 505)
7	Ramp	tensor (size: 32 × 1 × 505)
8	Convolution Layer	tensor (size: 64 × 1 × 477)
9	Pooling Layer	tensor (size: 64 × 1 × 120)
10	Ramp	tensor (size: 64 × 1 × 120)
11	Flatten Layer	vector (size: 7680)
12	Linear Layer	vector (size: 64)
13	Ramp	vector (size: 64)
14	Linear Layer	vector (size: 2)
15	Softmax Layer	vector (size: 2)
	Output	vector (size: 2)

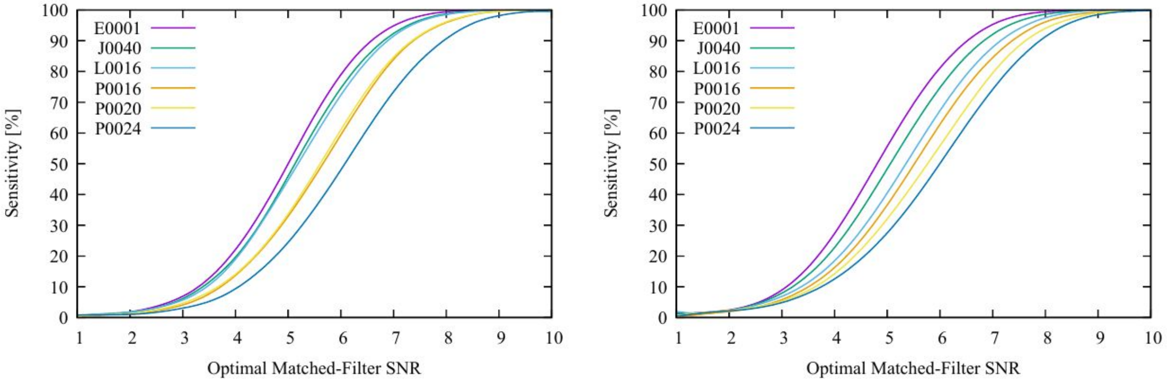




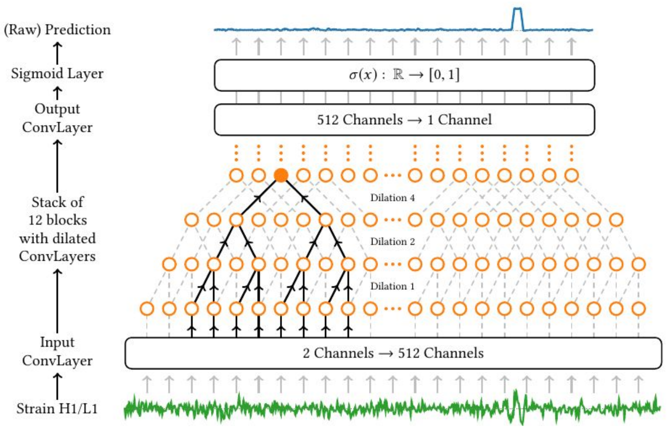


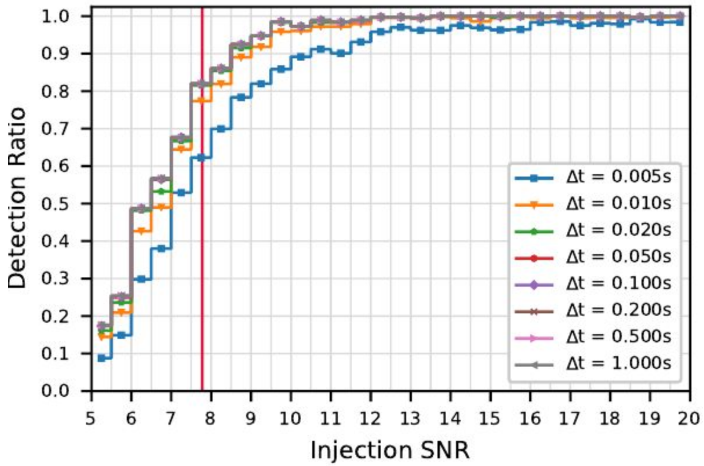
Detection of GW signals: Rebei et al (2019)

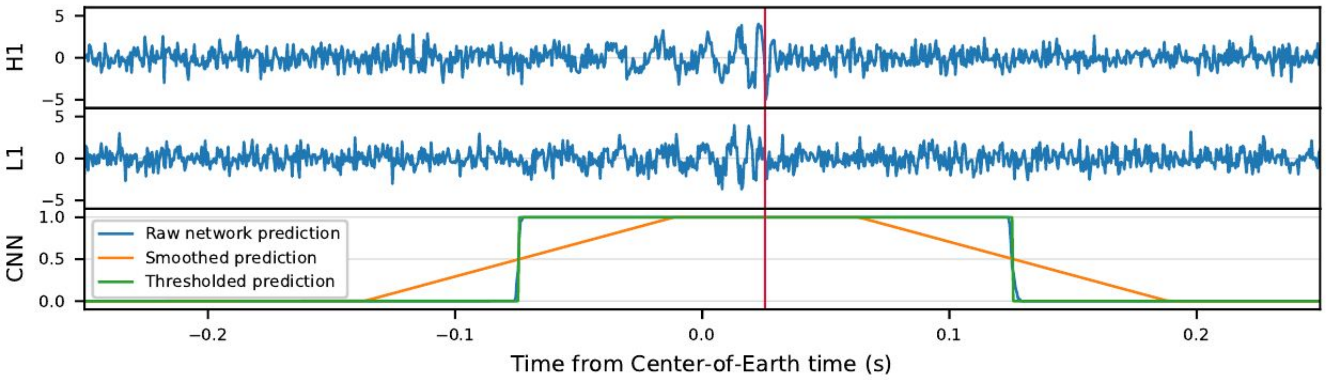




Detection of GW signals: Gebhard et al (2019)

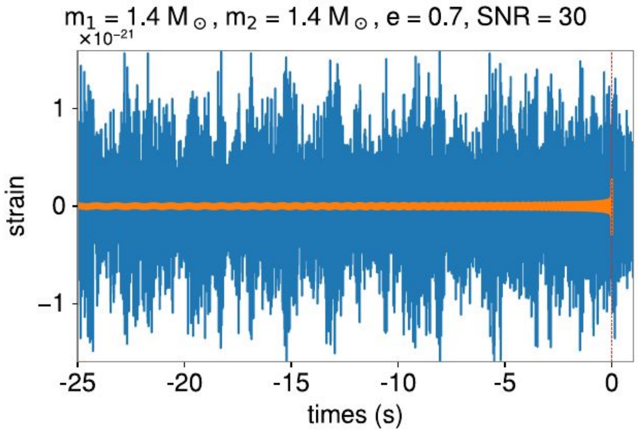


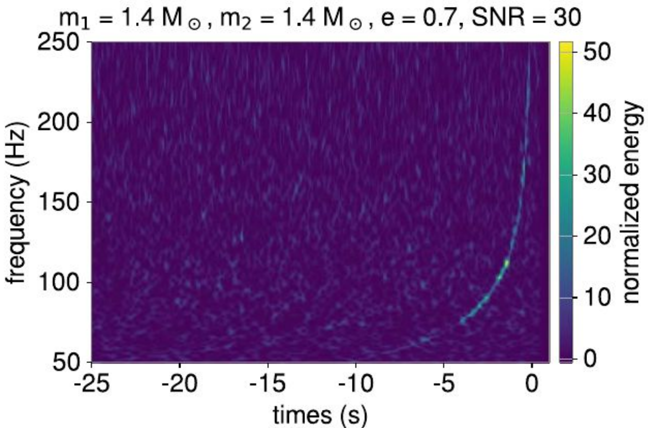


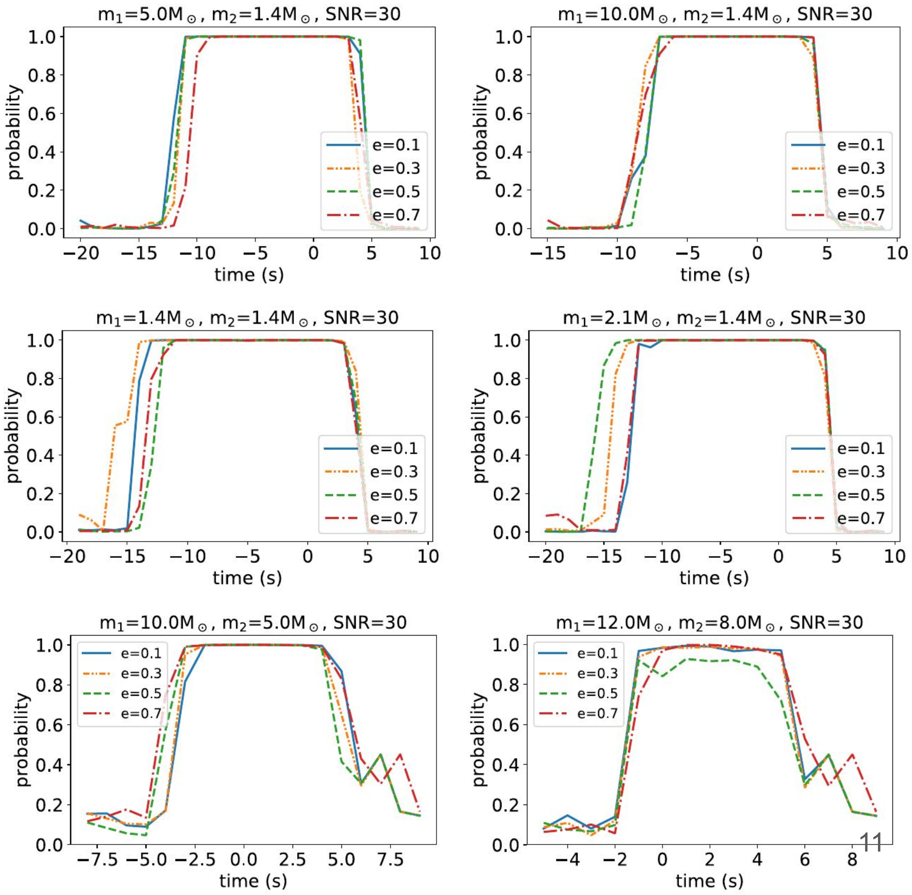


a) Results for GW150914.

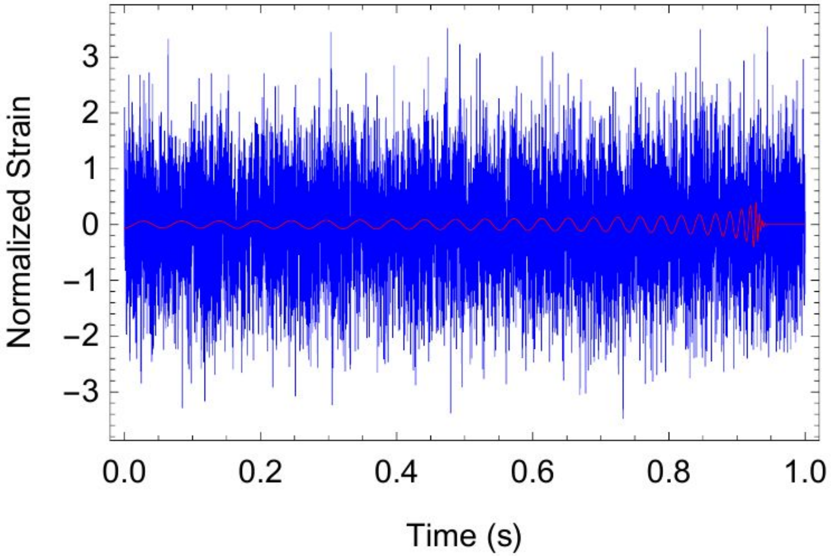
Forecasting (detection) of GW signals: Wei et al (2021)







2. Measuring source parameters



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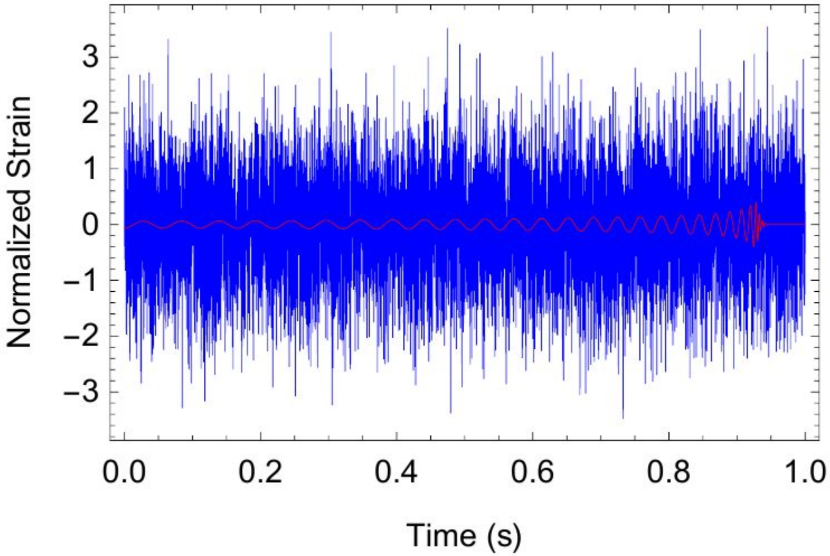

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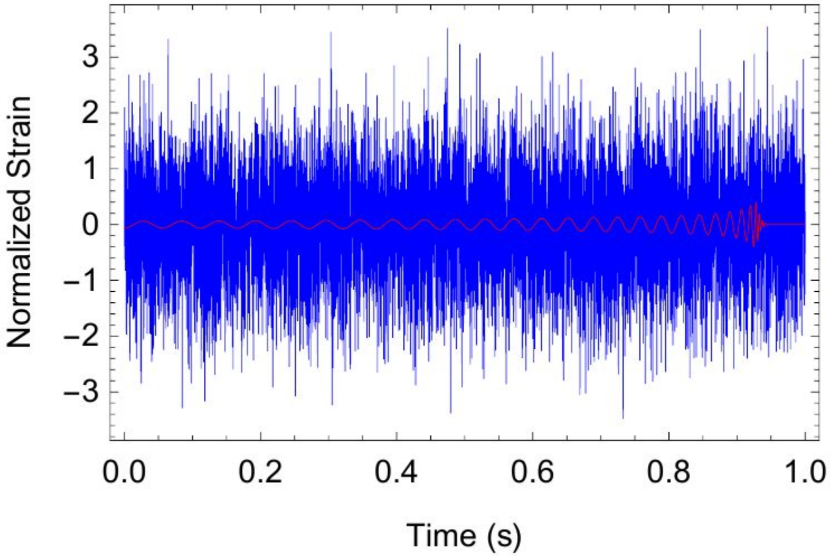
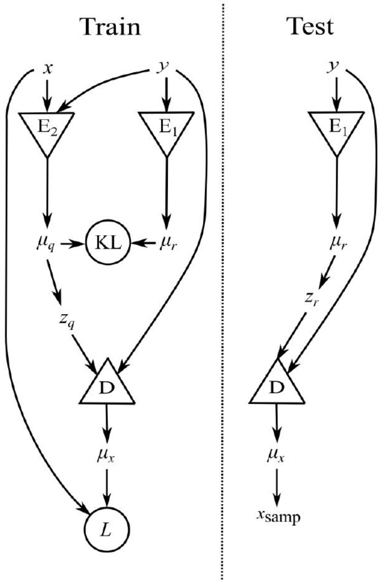


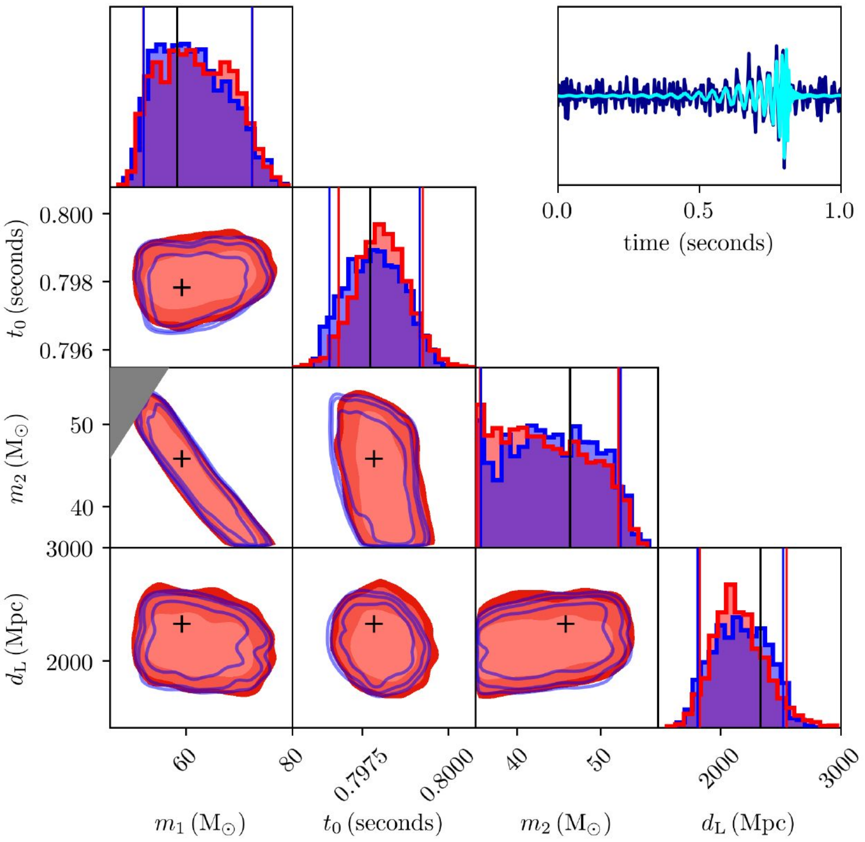
*Difficulties are the same as for the detection problem: **Signal is weaker than instrument noise**, we therefore need clever techniques for precisely characterizing the source of GW signals*

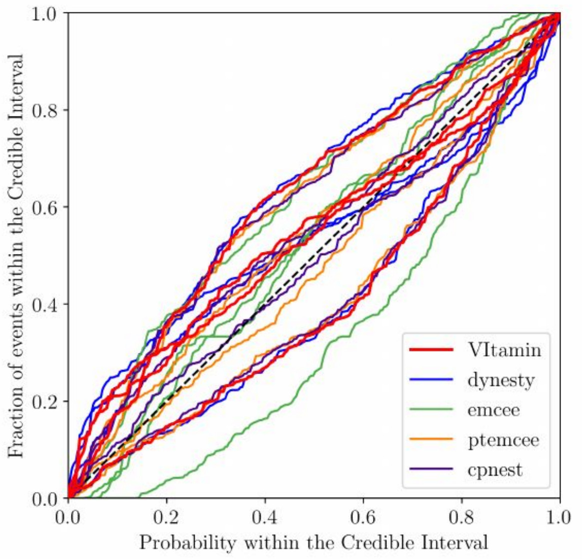
*Here also we **need low-latency** results since follow-up of GW events for EM counterparts needs prompt alerts to be sent to telescope partners!*

*Matched-filtering based Bayesian parameter estimation takes between **5 hours to 5 days per event**!*

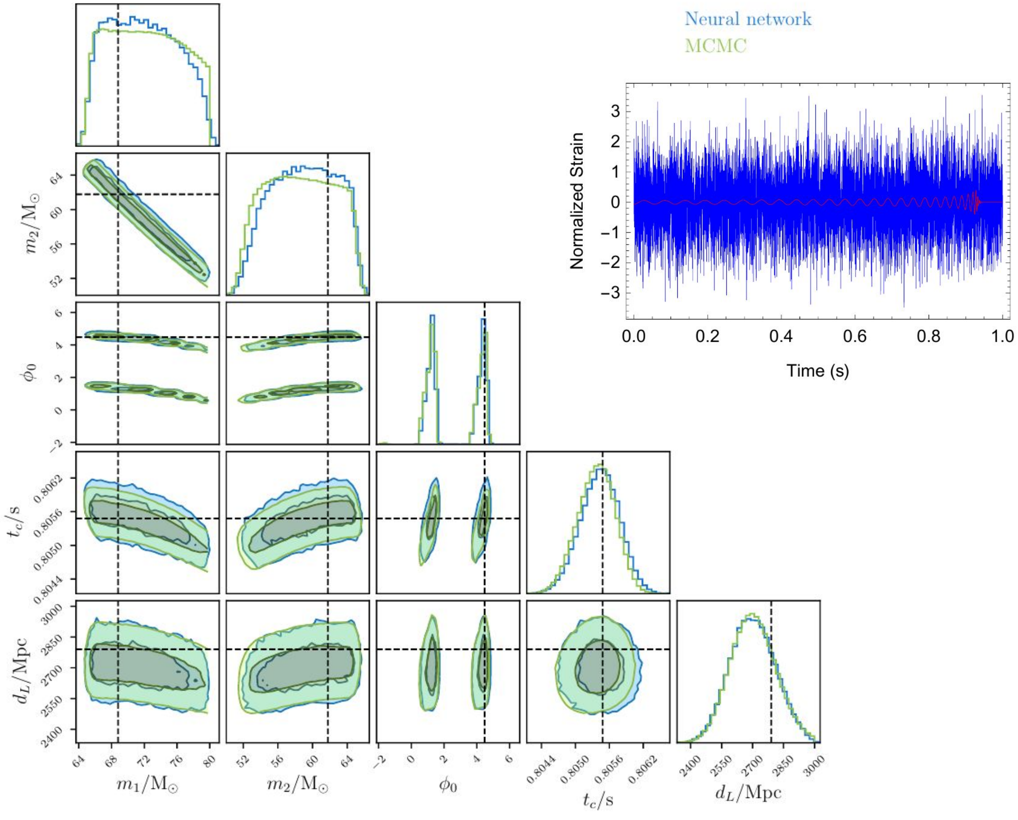
Measuring source parameters: Gabbard et al (2020)



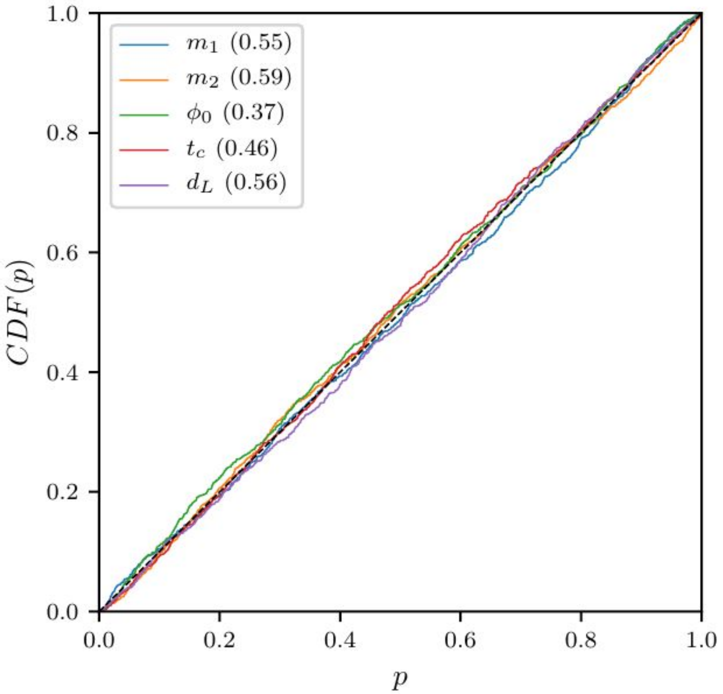




Measuring source parameters: Green et al (2020)

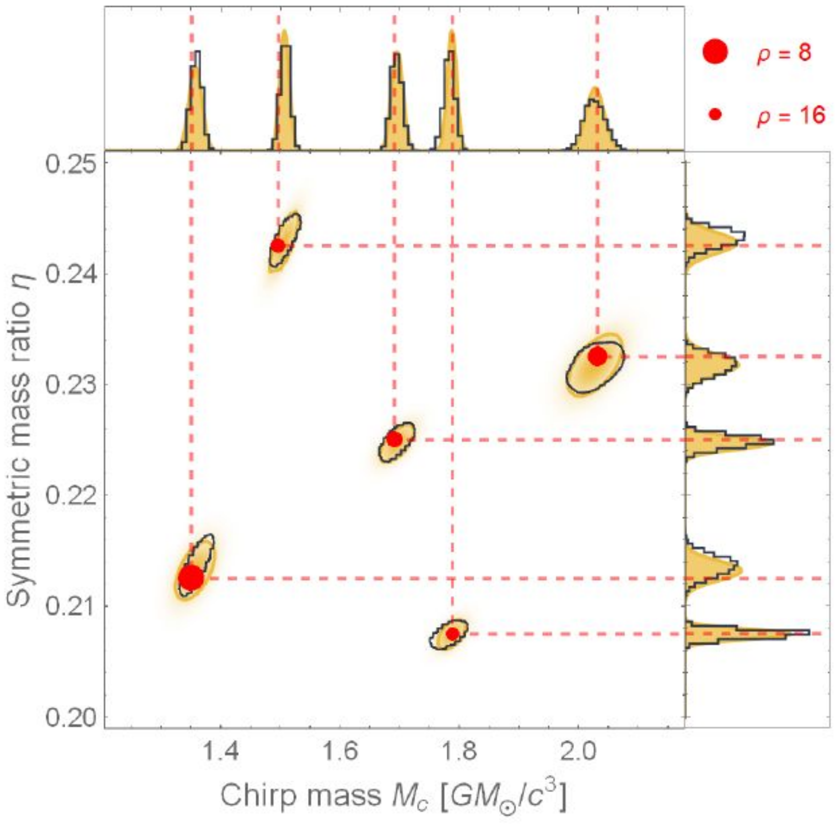


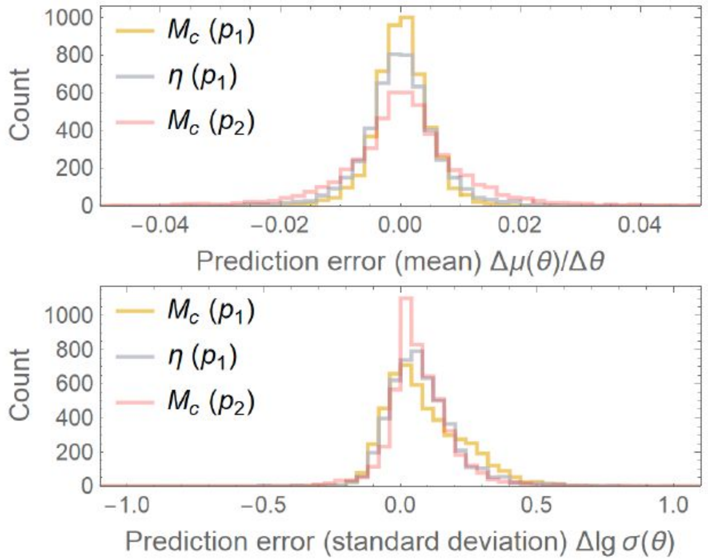
(c) CVAE+



(c) CVAE+

Measuring source parameters: Chua et al (2020)





Summary & Future Outlook

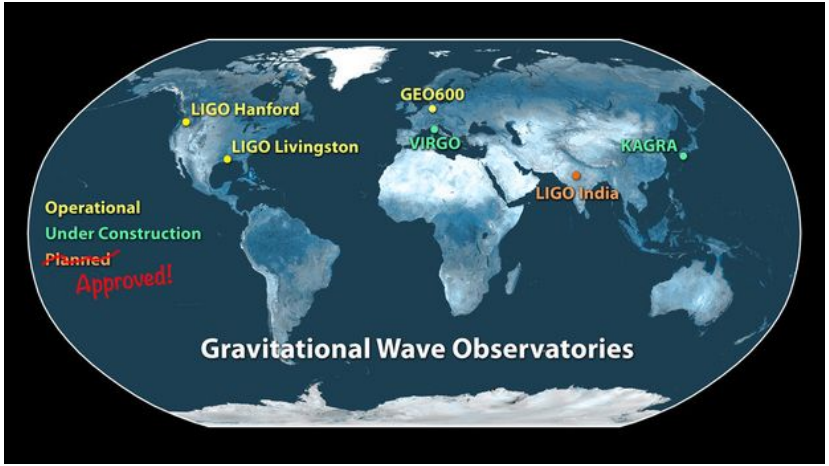
LIGO–India Scientific Collaboration

ML / AI can now be applied to:

- Low-latency detection of GW signals
- Measurement of source parameters from GW signals
- Characterization of GW detector noise transients

Future:

- Most of these applications are in **proof-of-concept** stage
- No sufficiently clear understanding **yet** of the
  (a) statistical confidences in AI detections, and
  (b) source parameter measures in Bayesian framework
  ⇒ More nuanced applications of AI needed
- AI-based methods **need to be scalable** to future networks of 5 detectors: HLVKI
- Development of AI based algos **needs substantial computing expertise & hardware**
- Discover yet-undetected signal types
- Develop GW signal models by solving PDEs with neural-network based operators



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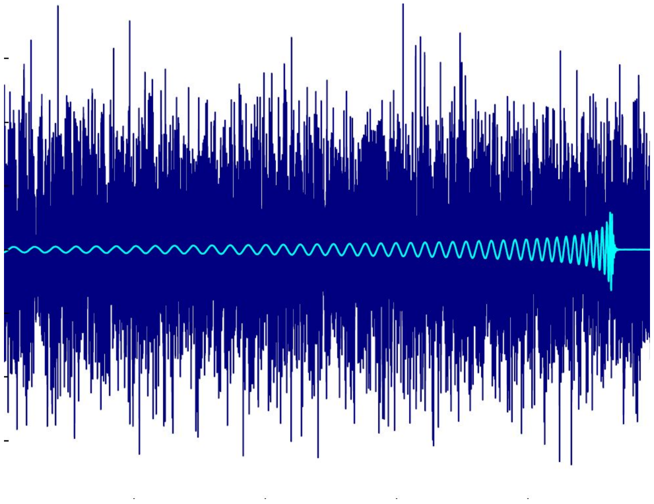
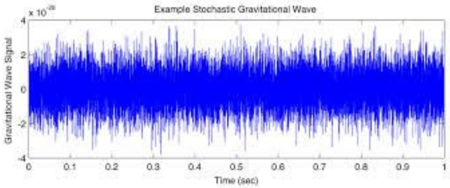
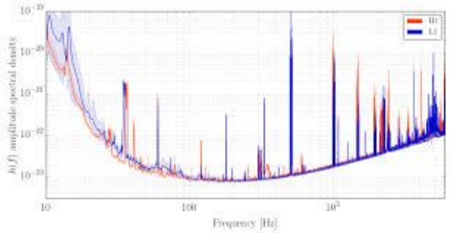
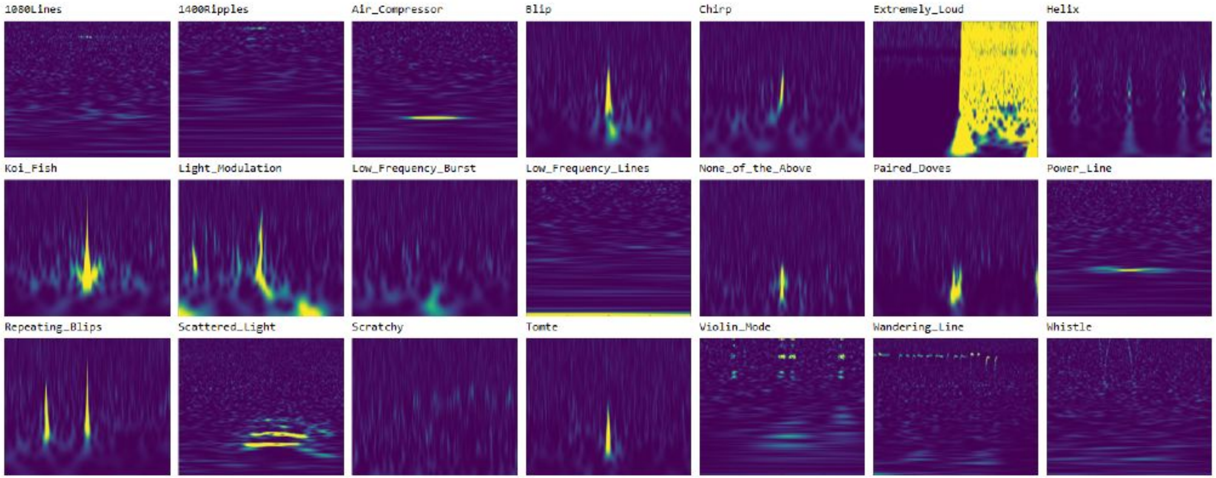
Questions?



Detector Noise Characterization: George et al (2017)







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