Gravitational Waves Detectors

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First MODE Workshop on Differentiable Programming

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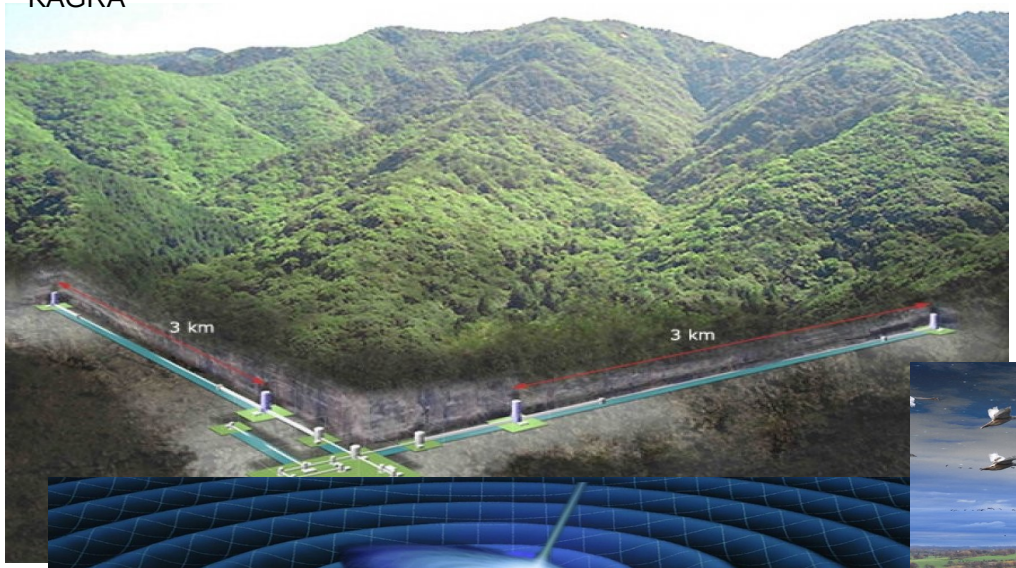
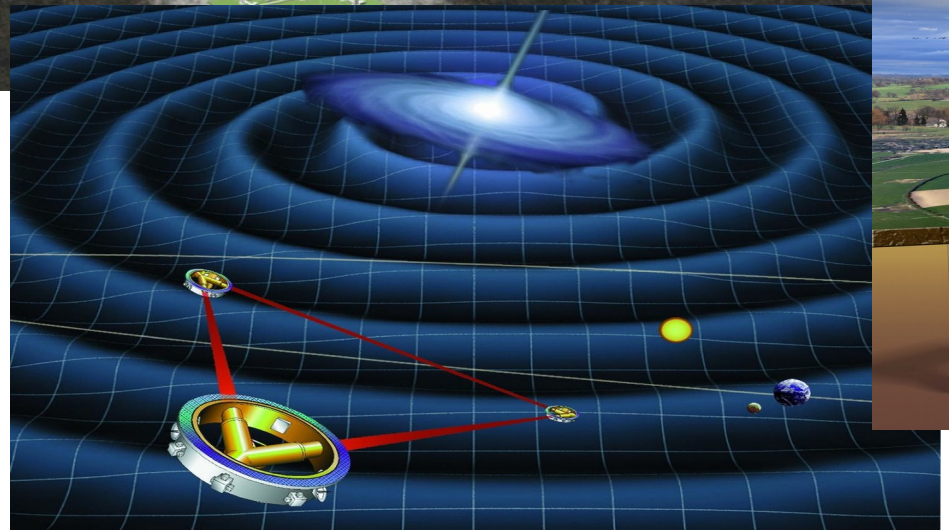
UNIVERSITÀ DEGLI STUDI DI PERUGIA
VIRGO
G2NET
cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY
INFN Sez. di Perugia

CP3, Louvain-la-Neuve 07/09/2021

Technologies

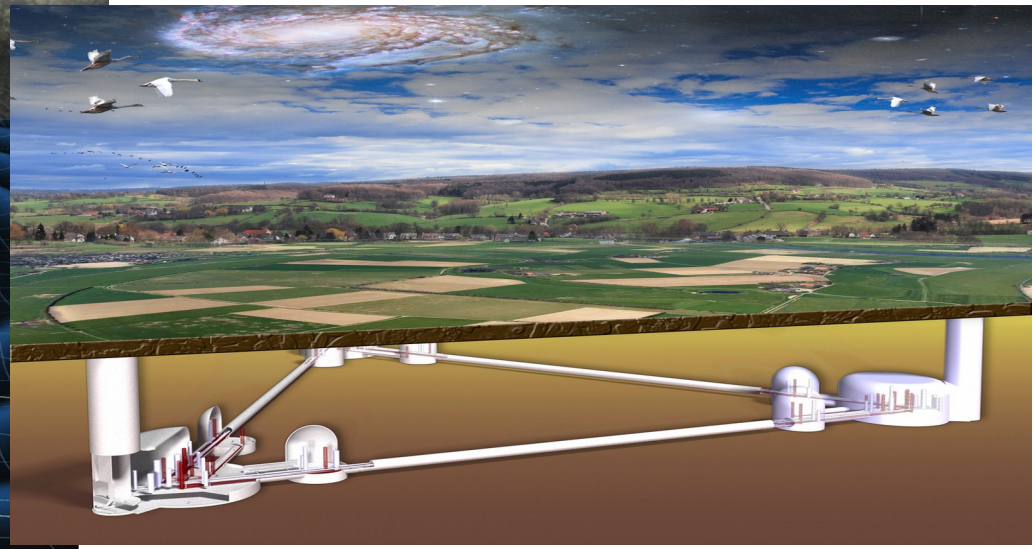
KAGRA





LISA

EINSTEIN TELESCOPE



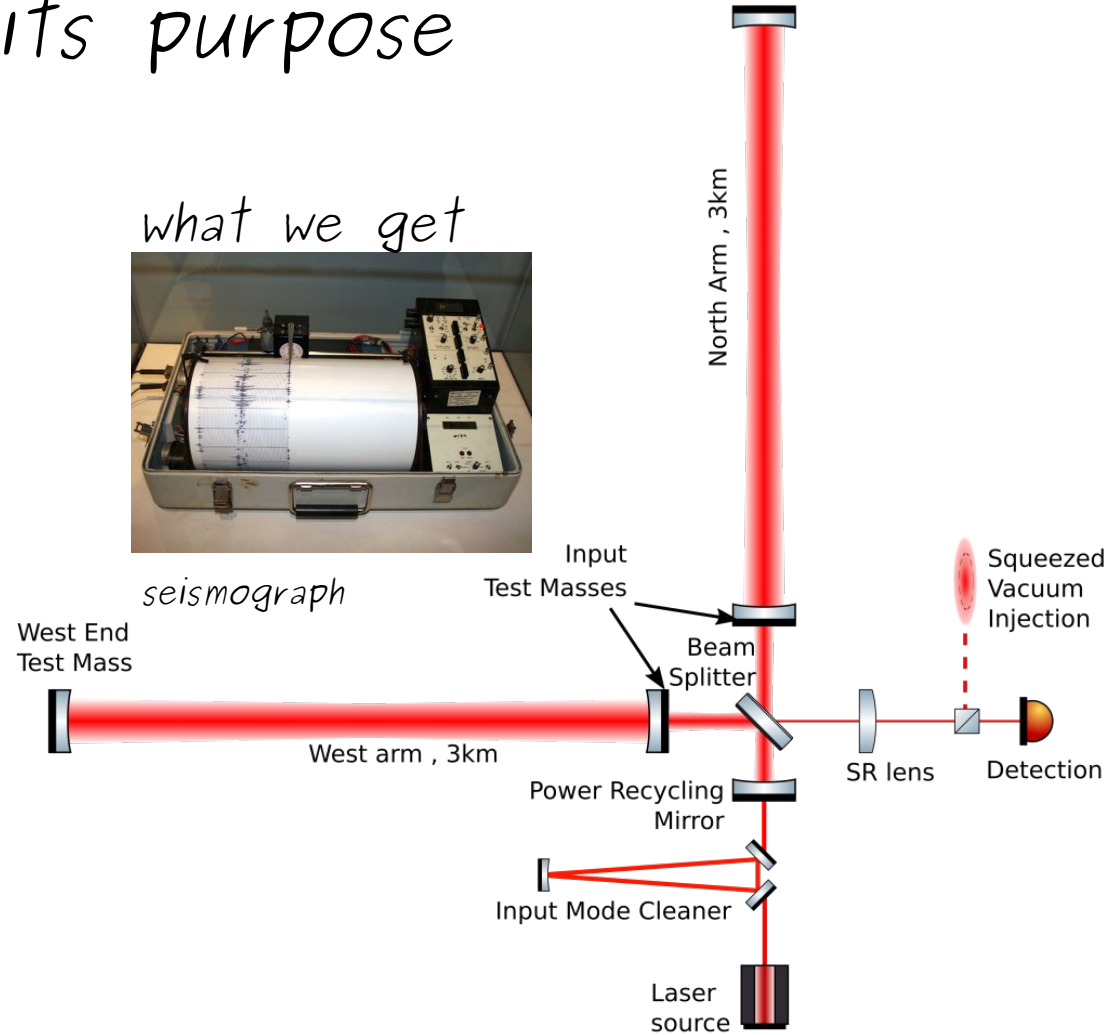
Detector and its purpose

what one may imagine

James Webb telescope
artistic interpretation

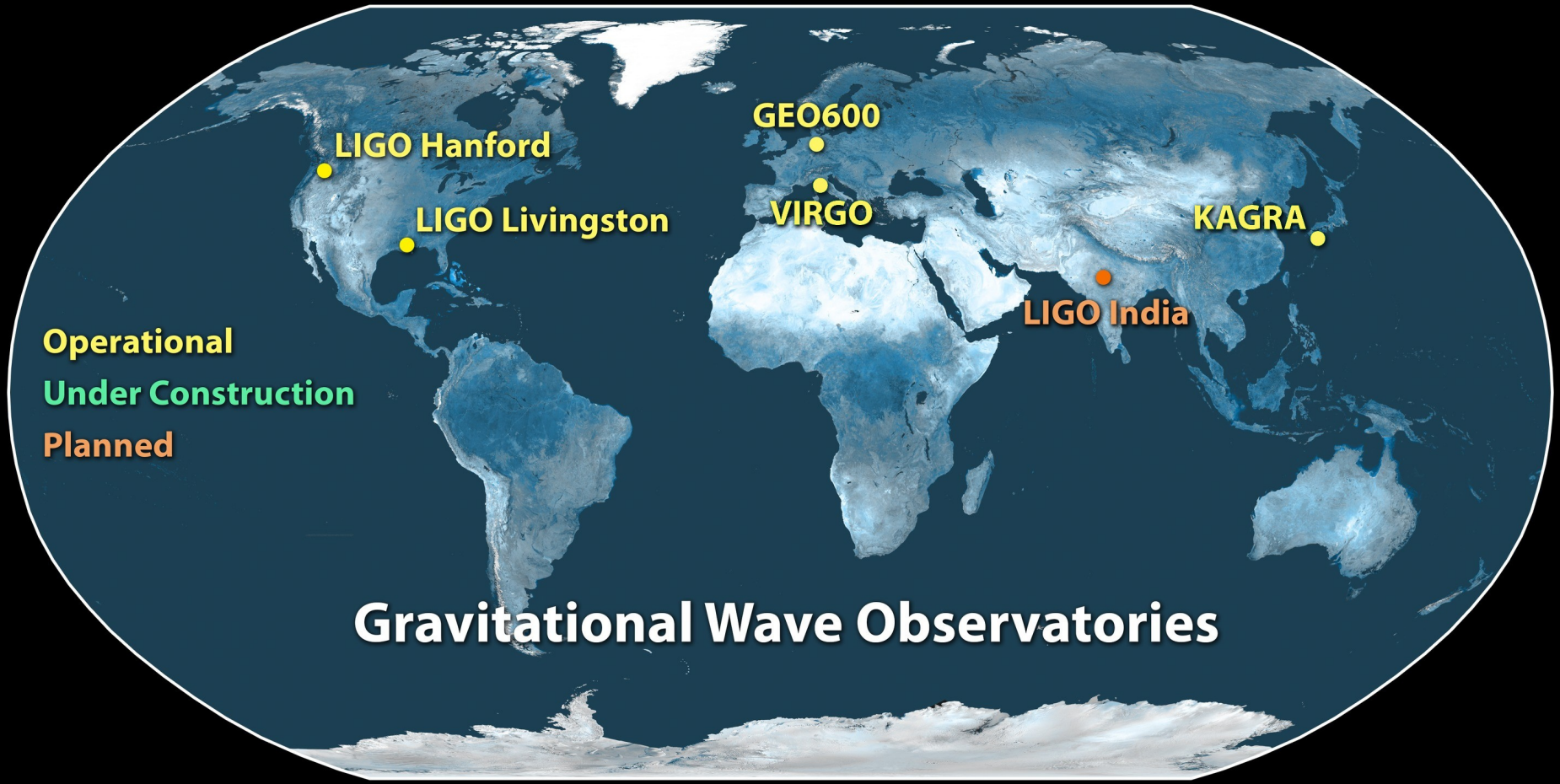
what we get

seismograph

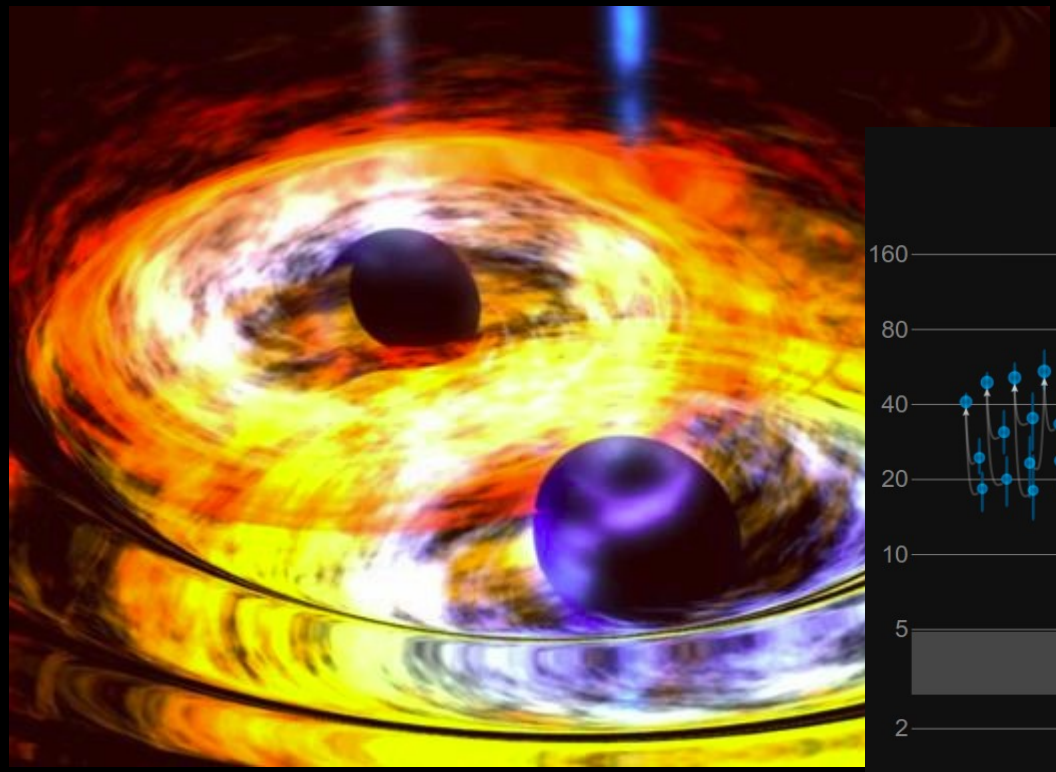


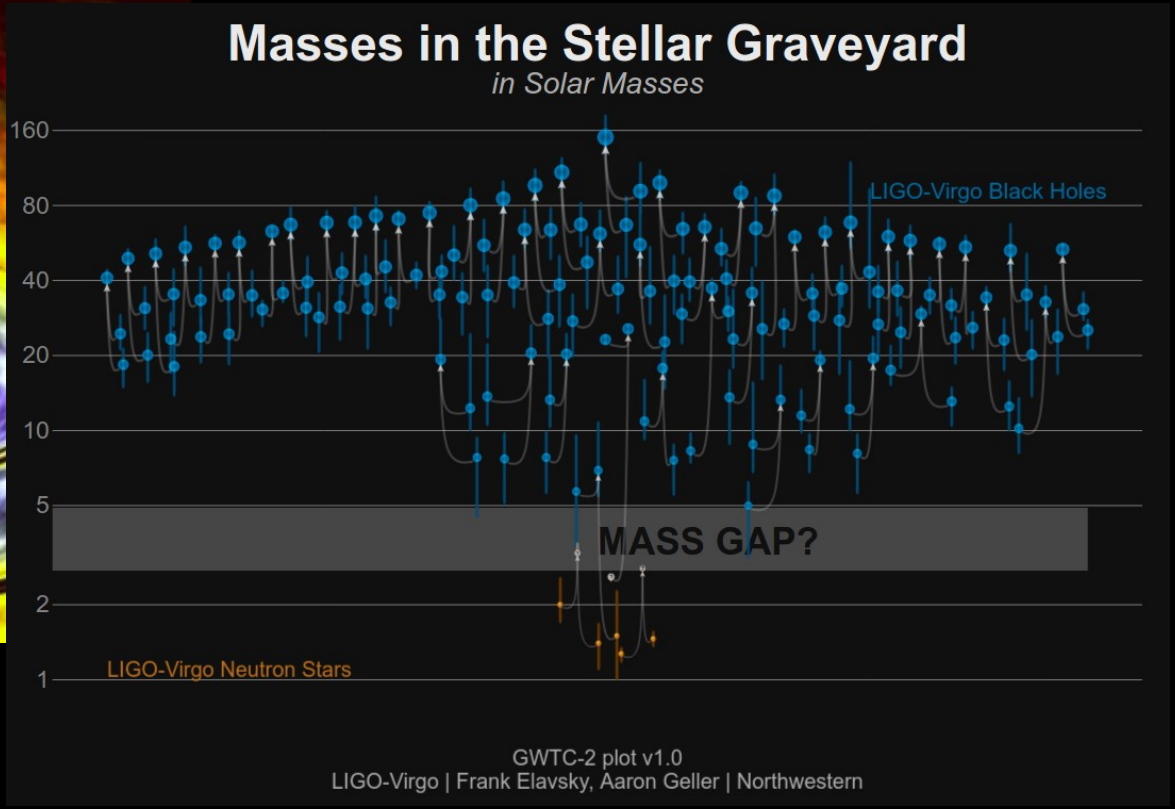
Advanced Virgo link

Network


LIGO Hanford
LIGO Livingston
GEO600
VIRGO
KAGRA
LIGO India
Operational
Under Construction
Planned
Gravitational Wave Observatories

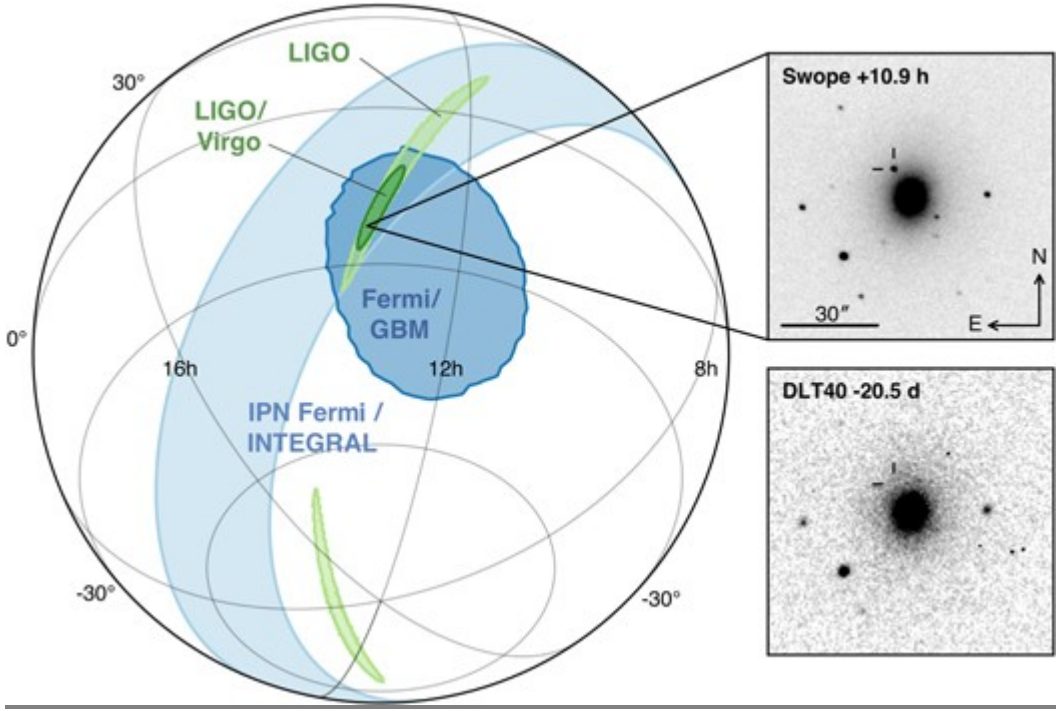
Observations

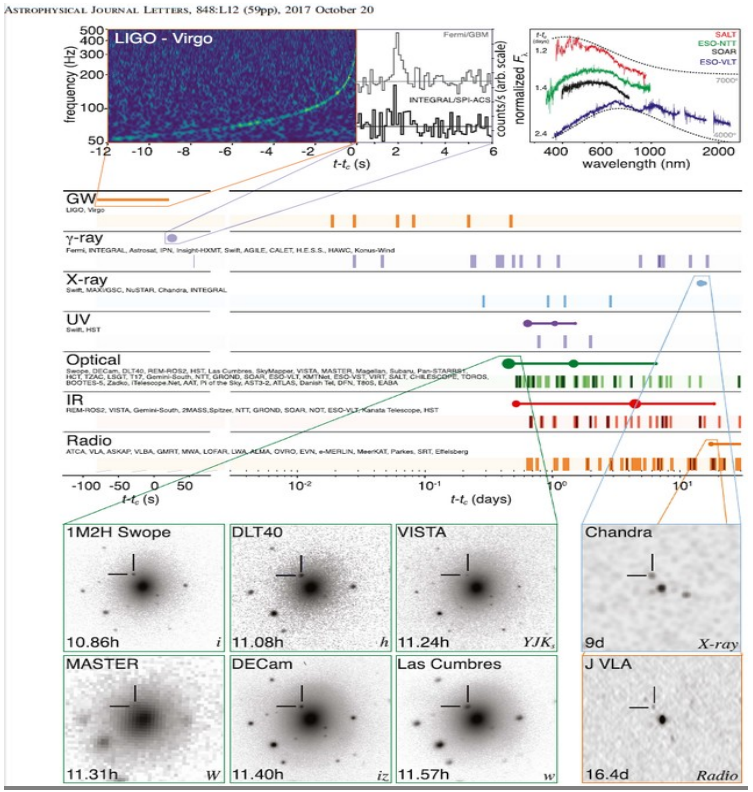




link to the interactive plot

Multi-messagner astronomy





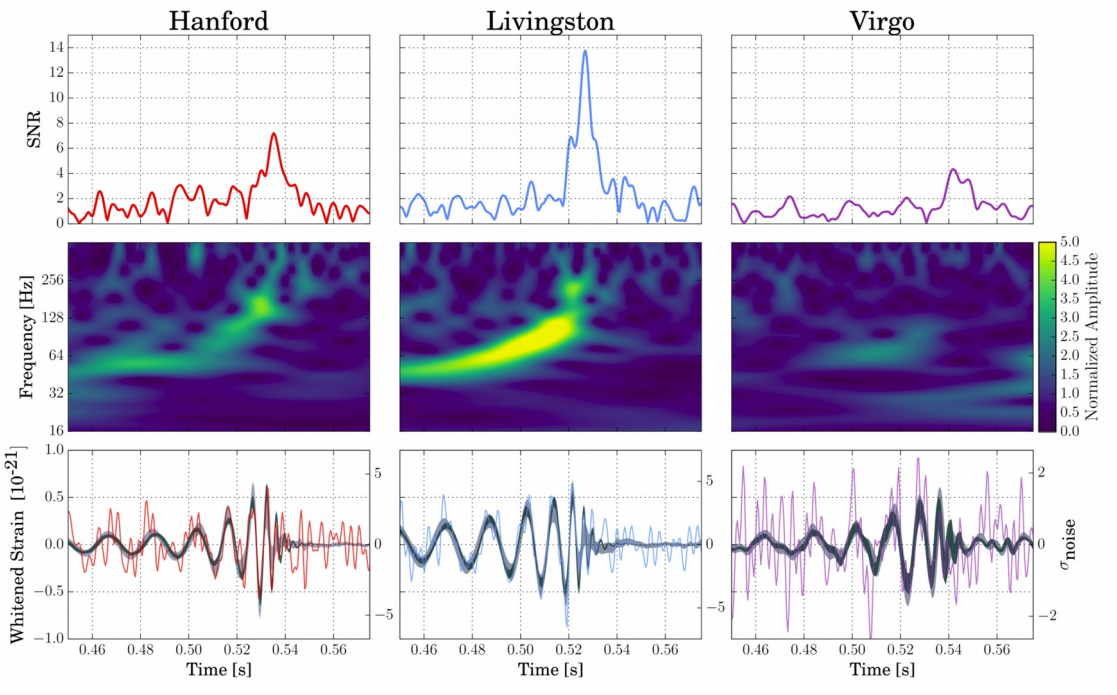
Multi-messenger Observations of a Binary Neutron Star Merger

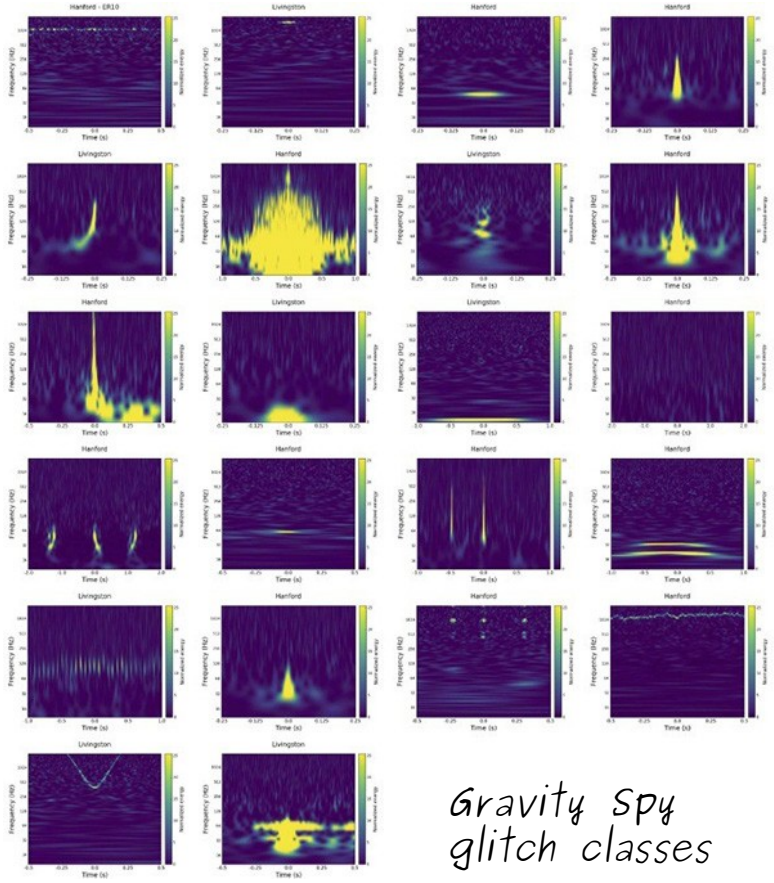
GW170817/GRB170817/AT2017gfo (NGC4993)

B. P. Abbott et al. 2017 ApJL 848 L12

Signal or glitch?

GW signal





Gravity Spy glitch classes

Differential programming application fields

- Data analysis
- Detector monitoring
- Detector optimisation
- Noise cancellation
- Detector control

- Low-latency Binaries Mergers search
- Parameter estimation
- Compact binary objects Population studies

g2net COST action

cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

CA17137

g2net – A network for Gravitational Waves, Geophysics and Machine Learning

- Gravitational wave searches
- Parameters estimation
- Glitch recognition and classification
- Disentanglement of GW from distinct sources
- etc…

G2NET

cost
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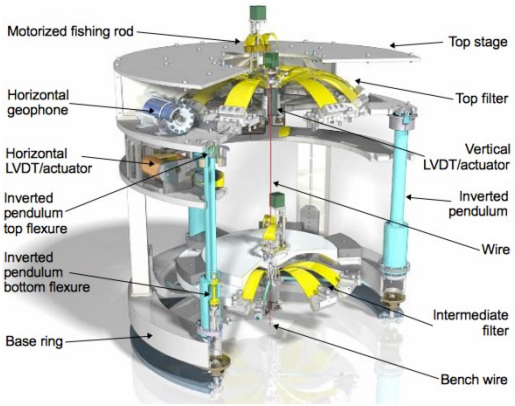
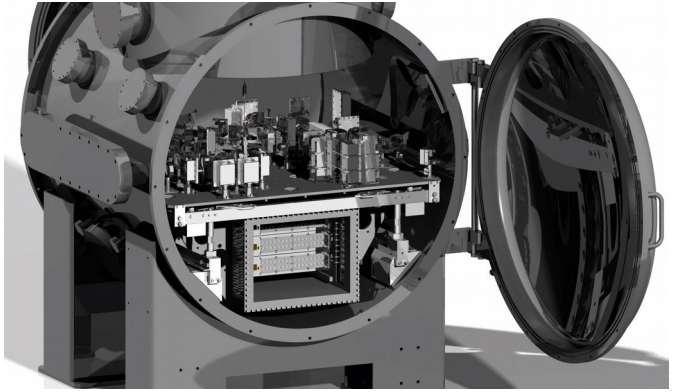
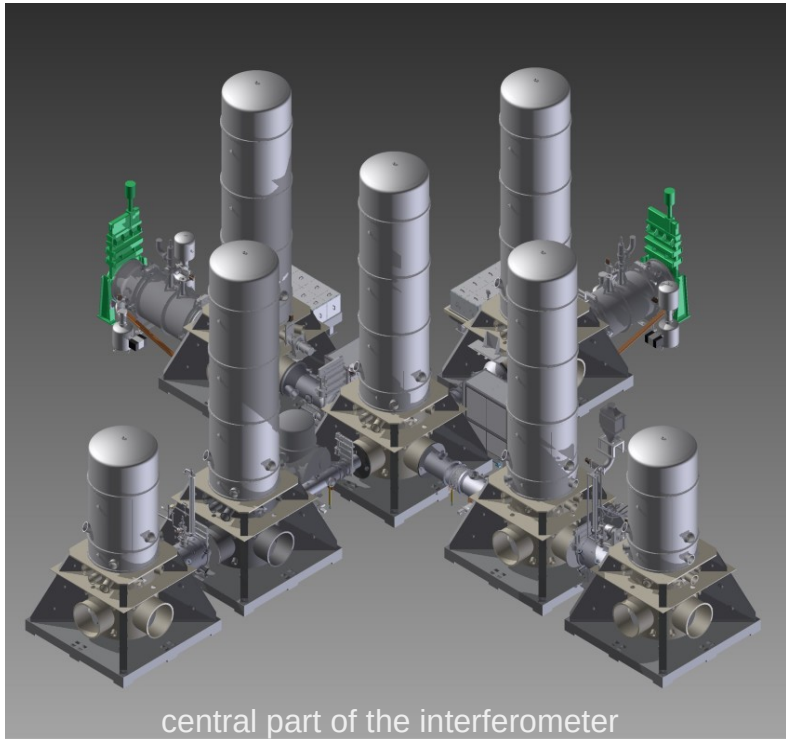
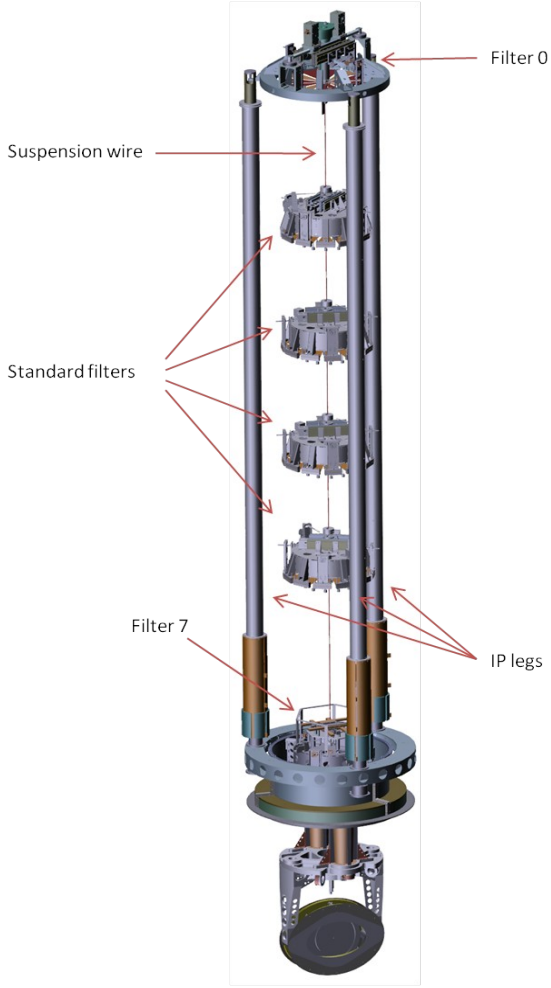
How to build recipe

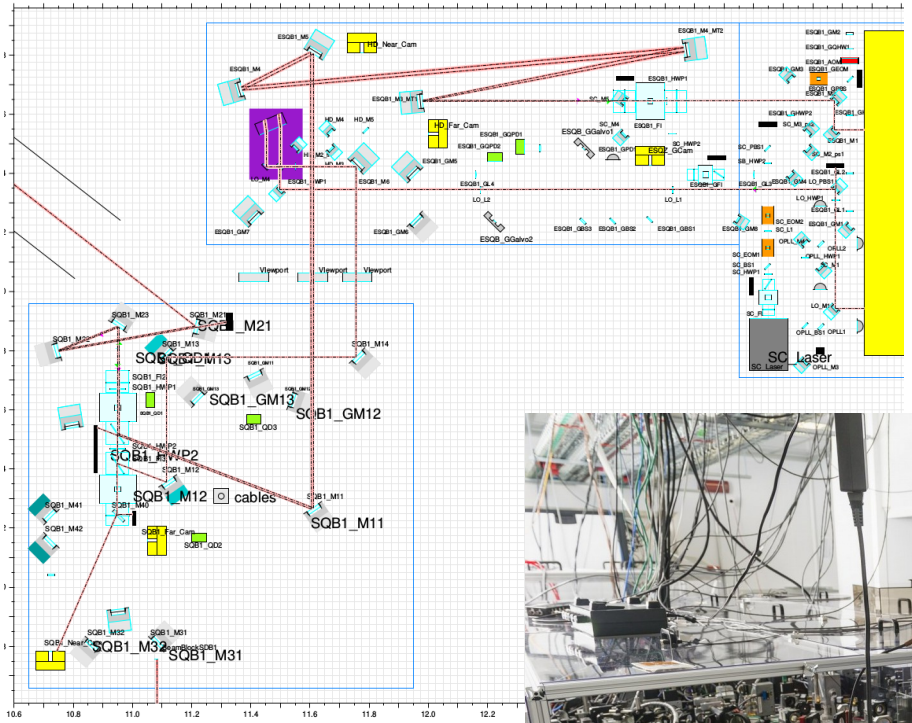




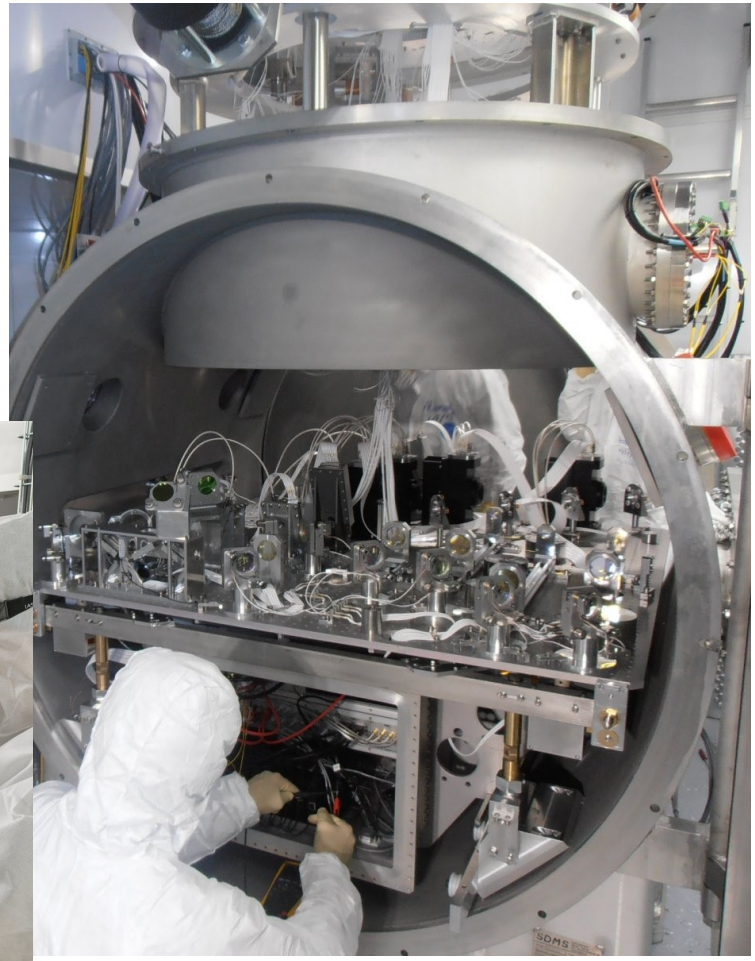




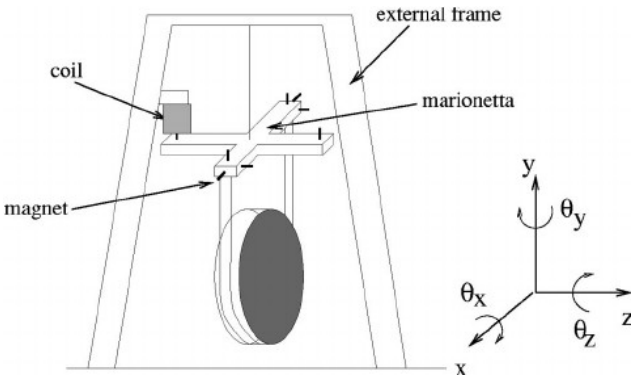
How to build recipe

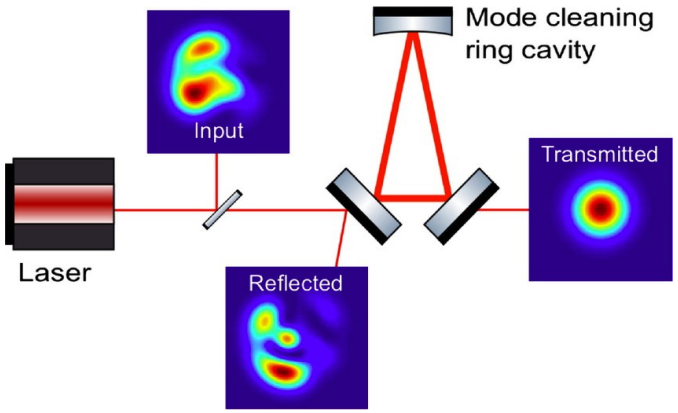


Suspended sQueezing Bench 1 (SQB1) & External Sque

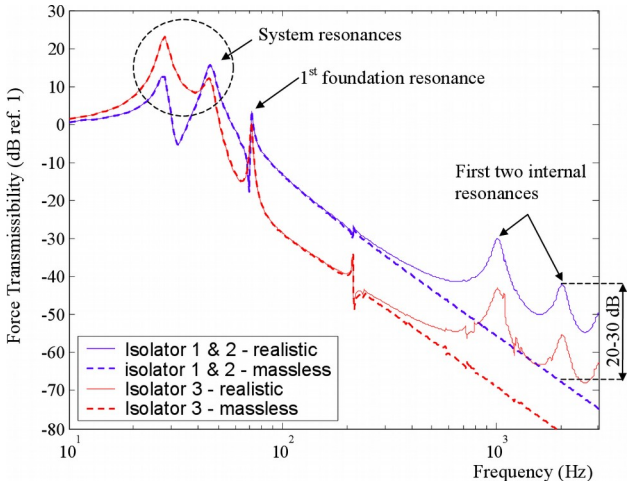


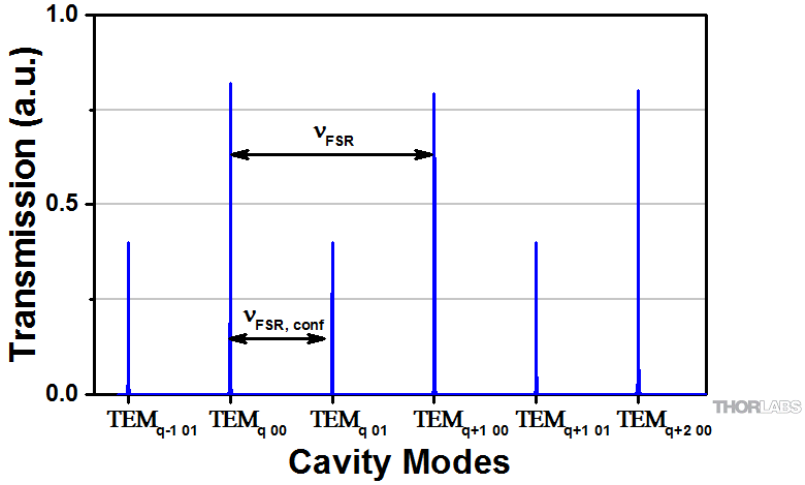
The task





controller design





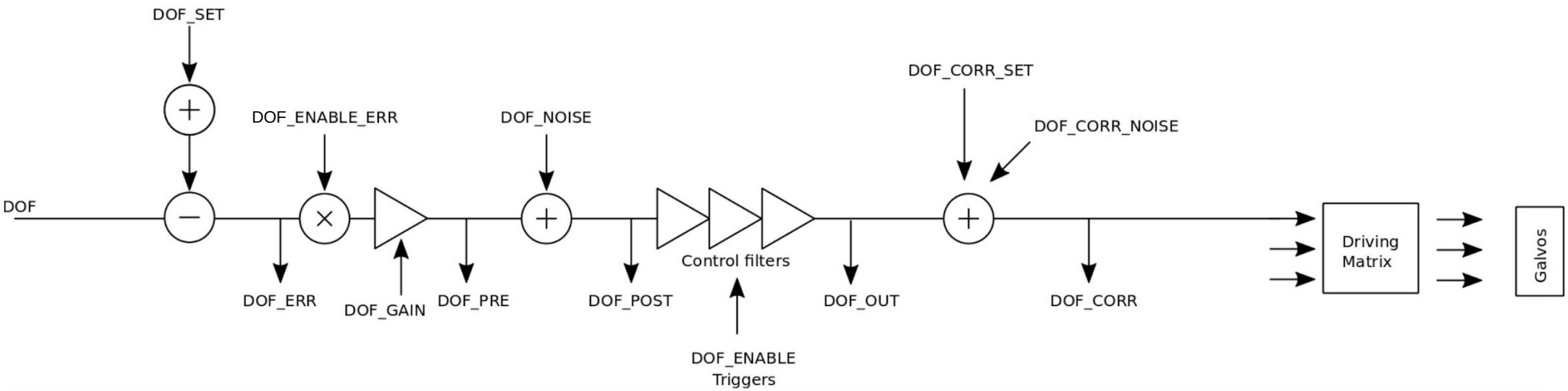
Sensors | Controllers | Actuators

- accelerometers
- photo-detectors
- LVDTs
- optical levers
- cameras
- etc.

- digital signal processing controllers

- laser tuning inputs
- coils
- piezoelectric stacks
- pico-motors
- optical modulators
- signal generators
- etc.

Typical local control FB loop



- blending
- boost filters
- driving matrices

digital up to signal demodulation

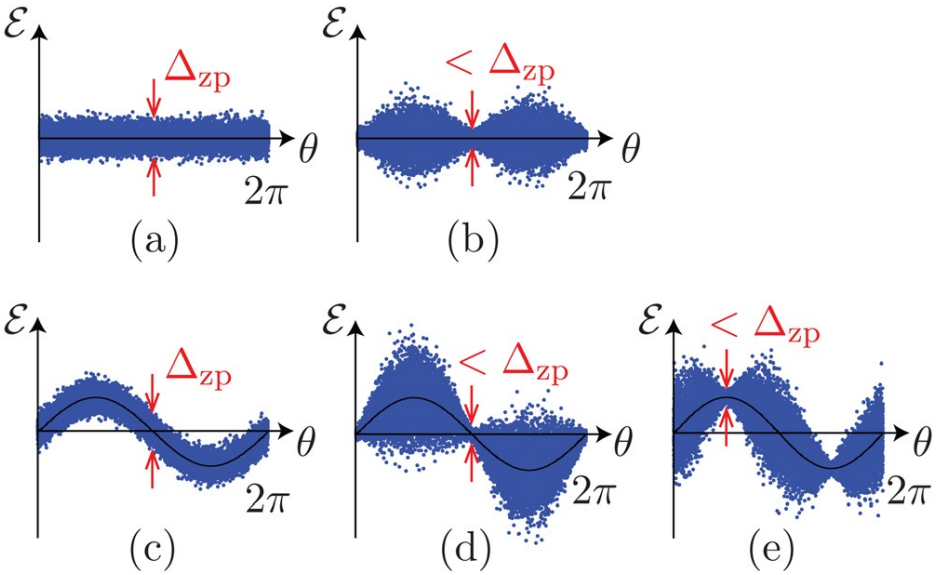
Easier than it seems
but more difficult than expected

- Classical control theory works

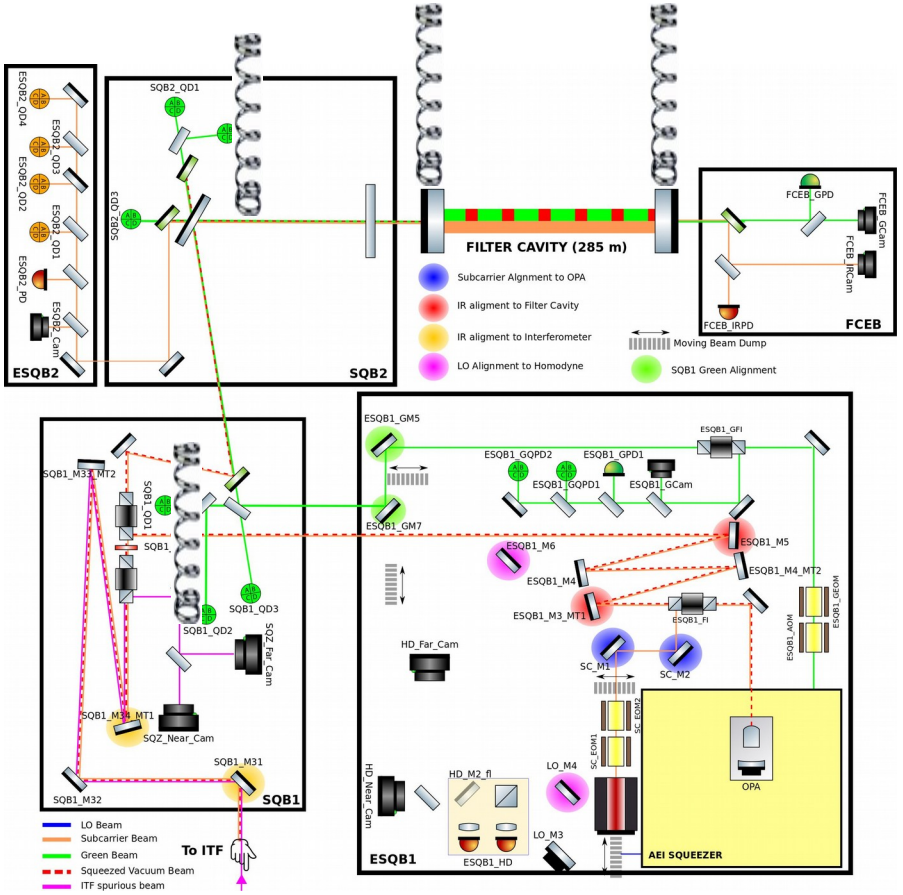
but

- Non-stationarity (temperature dependence, ageing)
- Non-linearity
- Cross-coupling

example: Quantum Noise Reduction subsystem



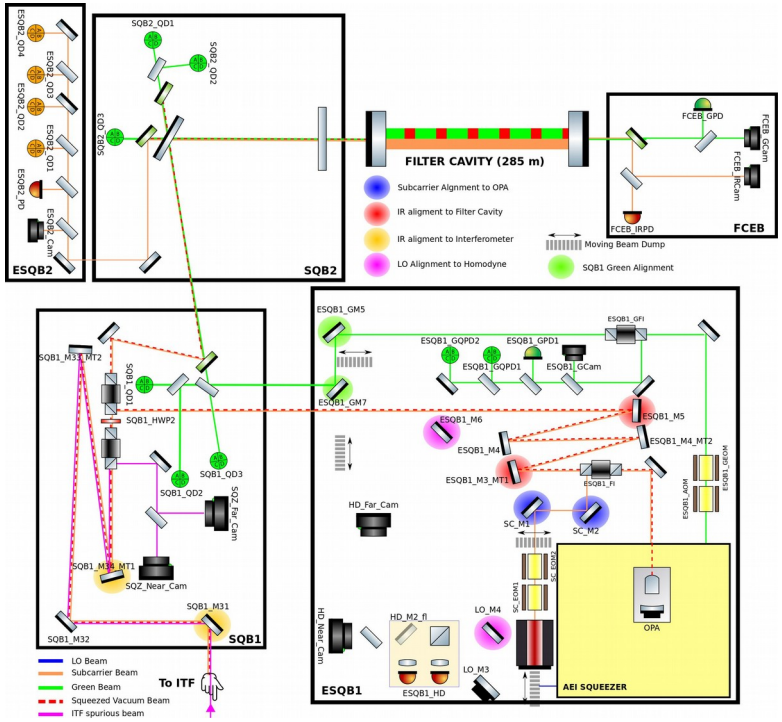
a) ground state; b) squeezed vacuum; c) coherent state; d) bright phase-squeezed state; e) bright amplitude squeezed state



F. Acernese et al. 2019 Phys. Rev. Lett. 123, 231108

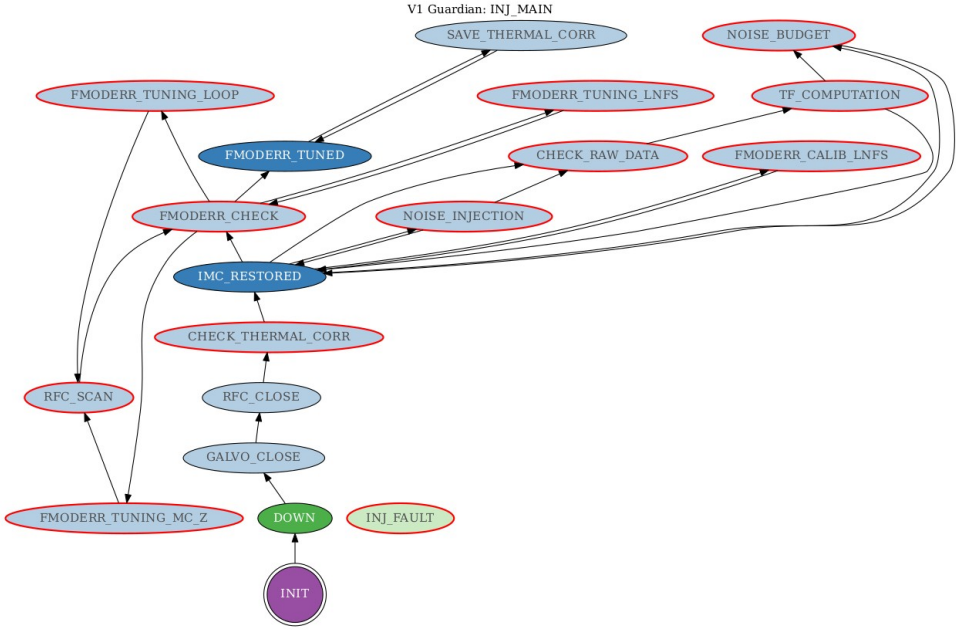
example: Quantum Noise Reduction subsystem

- Laser phase-lock loops x3
- Suspended bench controls x4
- Filter cavity alignment x2 (Gr+IR)
- Beam pointing x2 (Gr+IR)
- Homodyne detector alignment
- Green to IR frequency tuning
- Alignment with Virgo



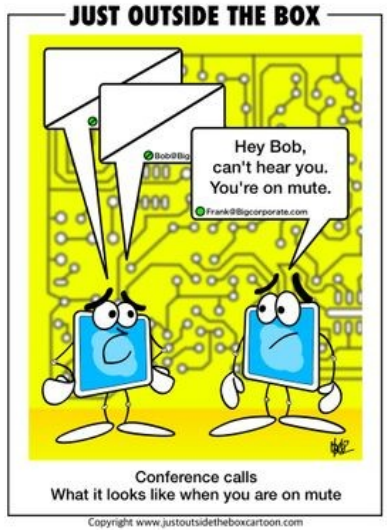
Orchestration

- hierarchization
- frequency multiplexing

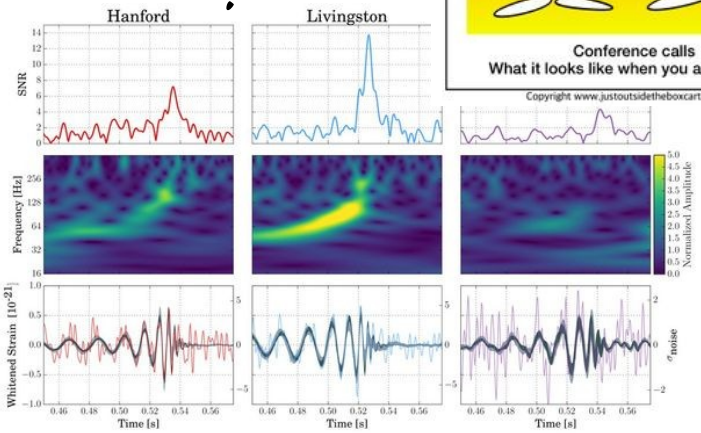


I would forget…

we count on operators' during the observation run



?



and on the rapid response team in case of probable detection

Toys in the sandbox

classic

- DAQ, UDSPT
- Algorithms for Control and Locking (Acl)
- dataDisplay
- Metatron

machine learning

- GW waveform recognition
- glitch recognition in the aux channels
- optimal strategies for Newtonian noise reduction
- …

Supplementary materials

- g2net publications list
- g2net WG3 training school on Machine Learning
- Scientific software&data exchange ESCAPE project
- Glitch recognition gym gravityspy.org
- Kaggle challenge on GW detection

Thank you for your attention!

This presentation is based upon work from COST Action CA17137,
supported by COST (European Cooperation in Science and Technology)

Support slides

g2net – A network for Gravitational Waves, Geophysics and Machine Learning

- Gravitational wave searches – Deep NN D. George arXiv:1701.00008
- Parameter estimation – A. Chua arXiv:1909.05966 & H. Gabbard arXiv:1909.06296
- Glitch recognition and classification – Convolutional NN M. Razzano arxiv:1803.09933 & Fractal analysis of data – M. Cavaglià
- Disentanglement of GW – F. Badaracco
- etc. in the ML review paper – E. Cuoco arXiv:2005.03745