Control of the gravitational wave interferometric detector Advanced Virgo

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Gravitational **W**aves (GW)

➔ Predicted by Einstein in 1916 → *consequence of General Relativity*

WHAT ARE GWs?

- *Perturbations of the metric* (geometry of space-time)
- *Caused by an acceleration of masses*
- Propagate at the *speed of light.*

WHY GWs ARE INTERESTING?

- **New source of astrophysical observations** → complementary to EM spectra + *new phenomena*
- **Test General Relativity**

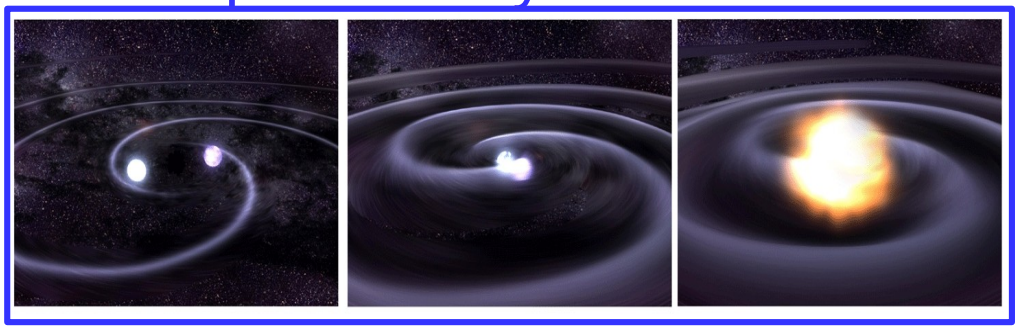
The 14th of September 2015 the Advanced LIGO detectors in Hanford and Livingston made the first detection of a GW

Sources of GW

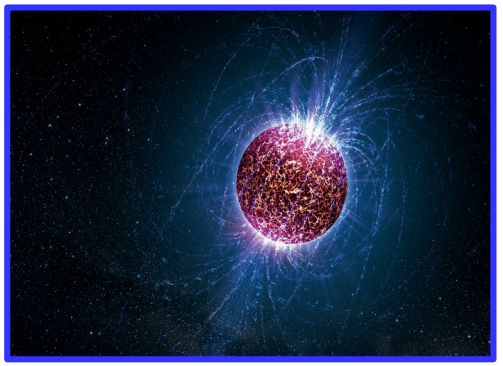
- **Emitted power:** *asymmetric* mass distribution, *compact* and *relativistic.*
- **Distance:** *h* decreases as *1/r*

Binary Neutron Star (BNS) @ 15 Mpc $h \sim 10^{-21}$

Compact Binary Coalescence

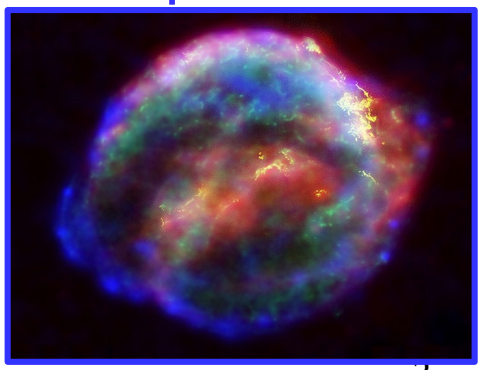


Some interesting sources for *ground-based GW detectors*



Rotating Neutron Star

Supernova



GW detection principle

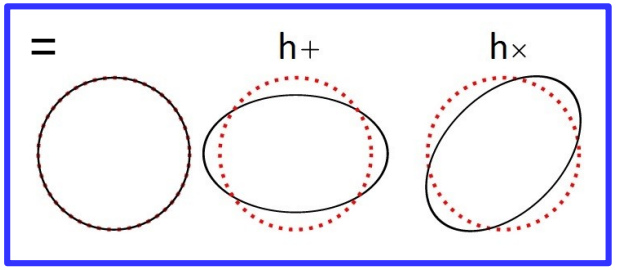
Mass that senses only the gravitational force

- **Effect** of the passage of a GW → *change on the distance between free masses*

$$\delta L / L \sim h$$

GW amplitude

- **Differential effect:**



MICHELSON INTERFEROMETER + SUSPENDED MIRRORS

Interference depends on the phase difference between the Michelson arms → *sensitive to length difference*

$$\delta\phi = \frac{2\pi}{\lambda}\delta L$$

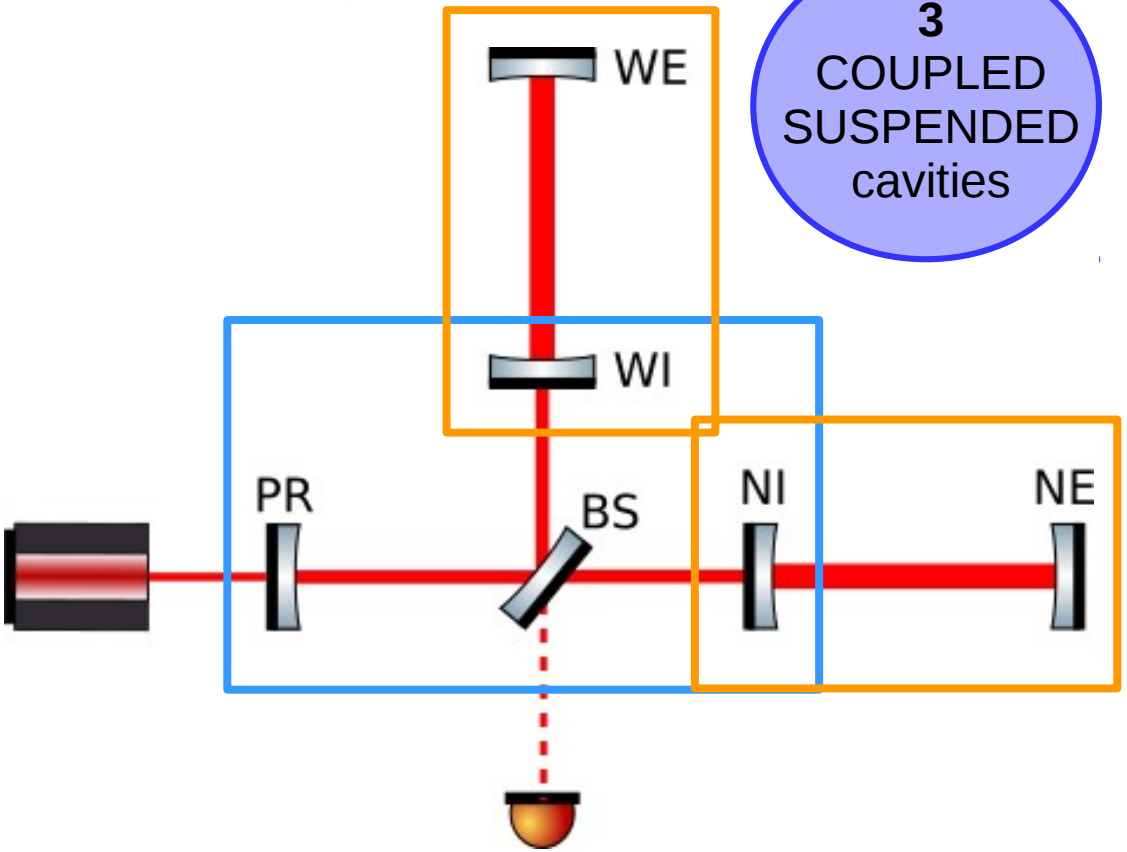
Change on the detected power

δP_{det}

GW detector working point

Sensitivity is limited by the ***shot noise***

Working point: Michelson in ***Dark Fringe***



3 COUPLED SUSPENDED cavities

Table top Michelson not enough sensitivity $h \sim 10^{-17}$

$$h_{shot} \propto 1 / (L \cdot \sqrt{P})$$

IMPROVEMENTS:

1) Fabry-Perot cavities in the arms (3 km) → increase the optical path

2) Power Recycling cavity → increase the circulating power

Interferometer **S**ensing and **C**ontrol (ISC)

TARGET:

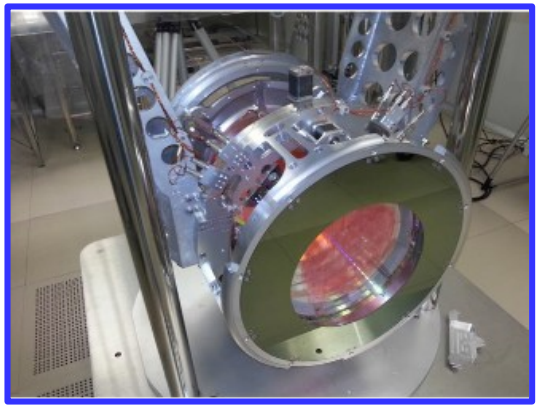
Bring the interferometer to its working point in a reliable and controlled way

PROBLEM:

- Residual seismic noise (*~1μm rms, ~1μm/s*) moves the mirrors both angularly and longitudinally → individual working point is crossed in a random way

- **Active control** is necessary to keep the ITF at its working point
  - *4 longitudinal* DOFs (lengths) + *frequency stabilization* (laser)
  - *16 angular* DOFs

2nd generation of GW detectors

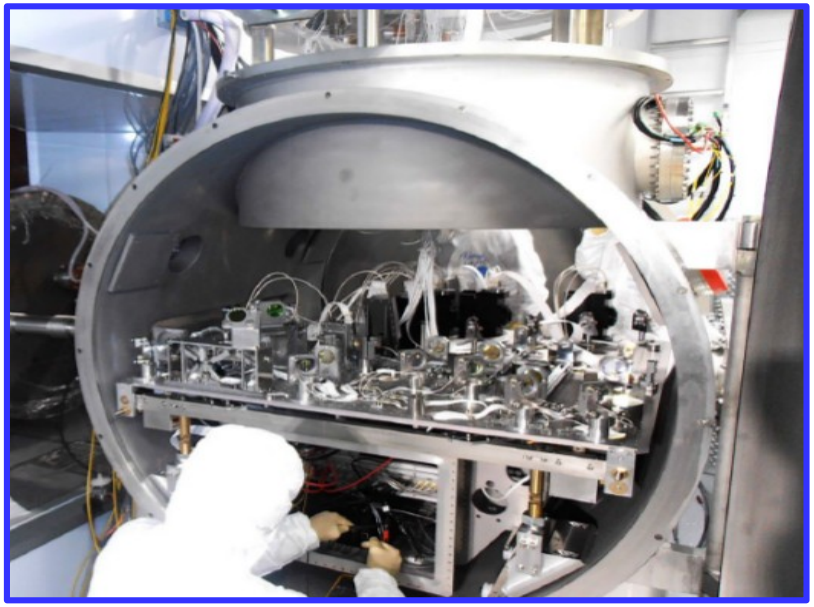


- 1st generation (until 2011) served as a *proof of the working principle*
  - No detection was made → 2nd generation improve sensitivity by a factor 10!

Advanced detectors added a set of major upgrades to lower the limiting noises (shot noise, thermal noise...) and increase the sensitivity

Changes affecting ISC

- **Increase of finesse** in the arm cavities
- Change of **arm cavities geometry**
- **Digital** loop for **frequency stabilization**
- Change of **PRC geometry**

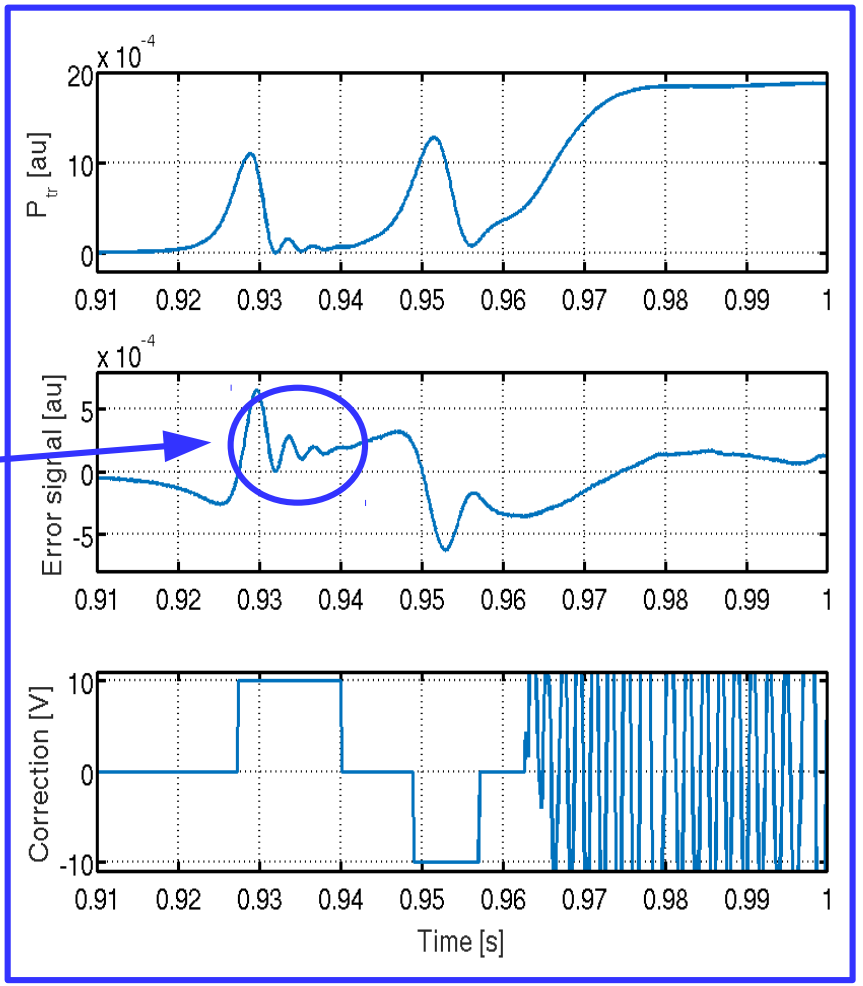


Thesis work

Advanced Virgo interferometer can be controlled in a reliable and repeatable way

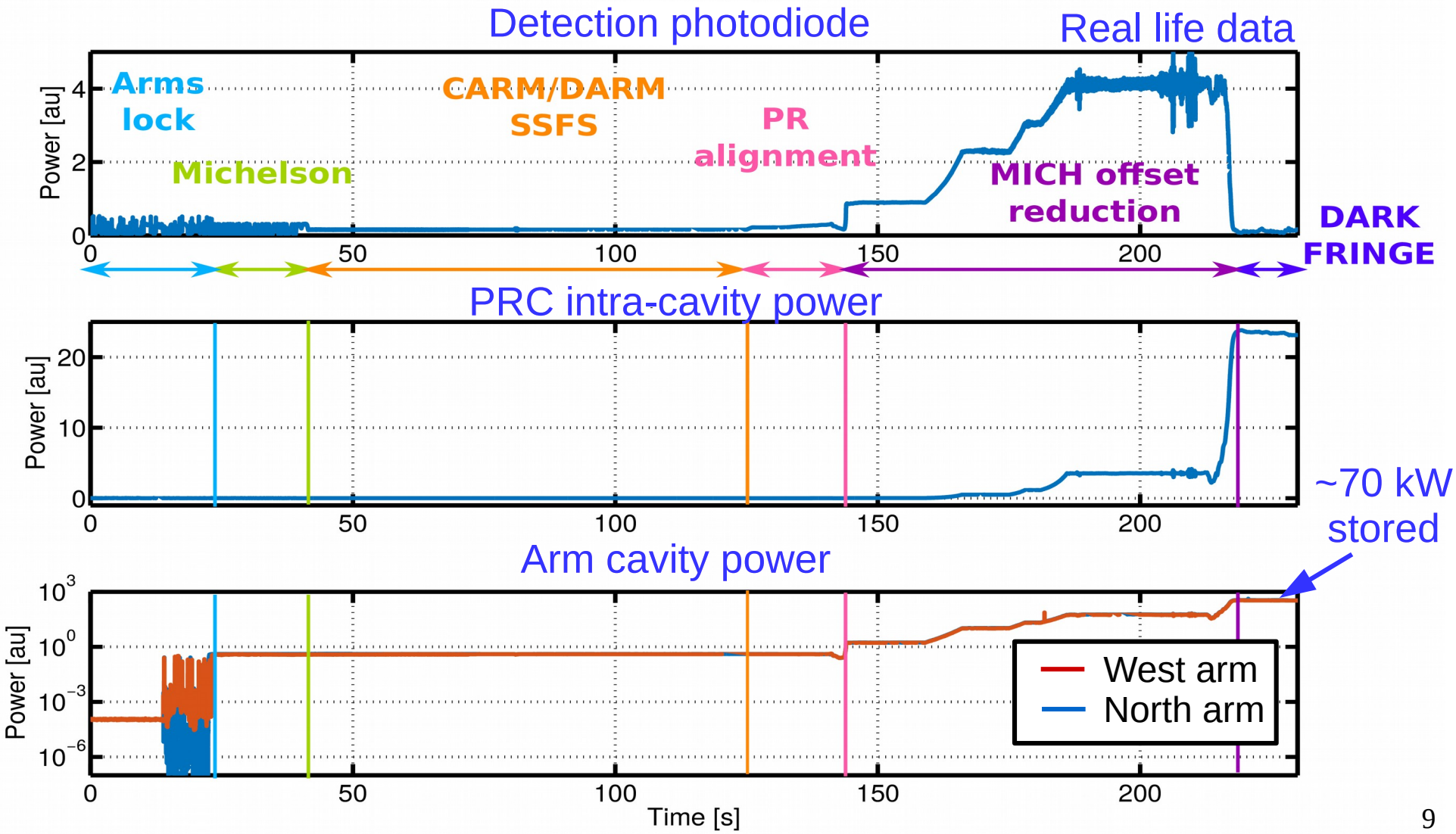
- Analysis of the impact of the upgrades on the control of the ITF using different **simulations** → Spot challenges
- **Analysis of the solutions** proposed
- **Practical implementation** during one-year commissioning
  - Dynamical effects
  - Stability problems
  - More complex alignment
  - New frequency stabilization scheme
  - Coupling between error signals
  - Power variations

Arm cavity control using Guided Lock – Real data



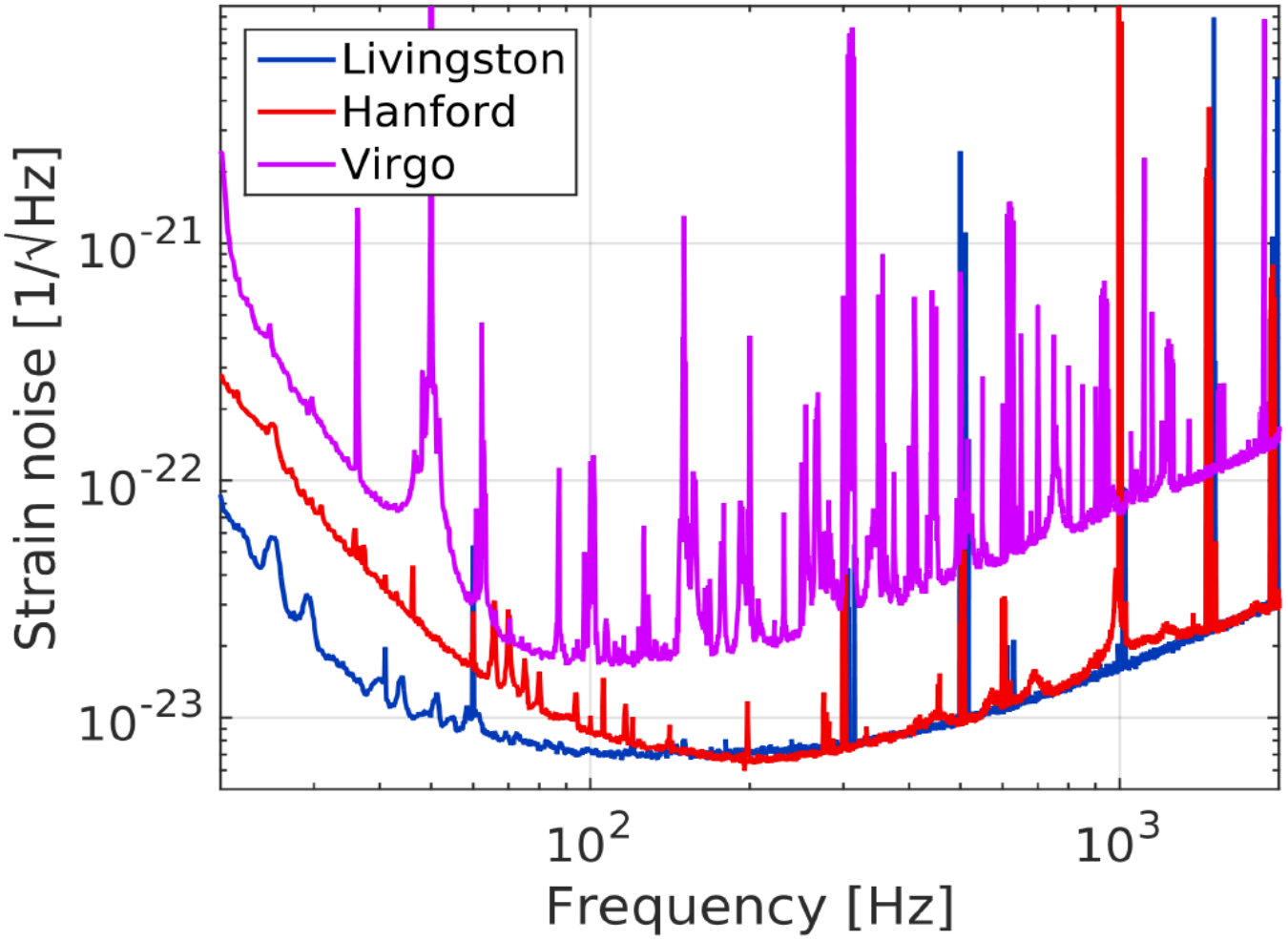
Lock acquisition sequence

- Once the problems previously presented were solved, the **lock acquisition sequence became a robust and repeatable**



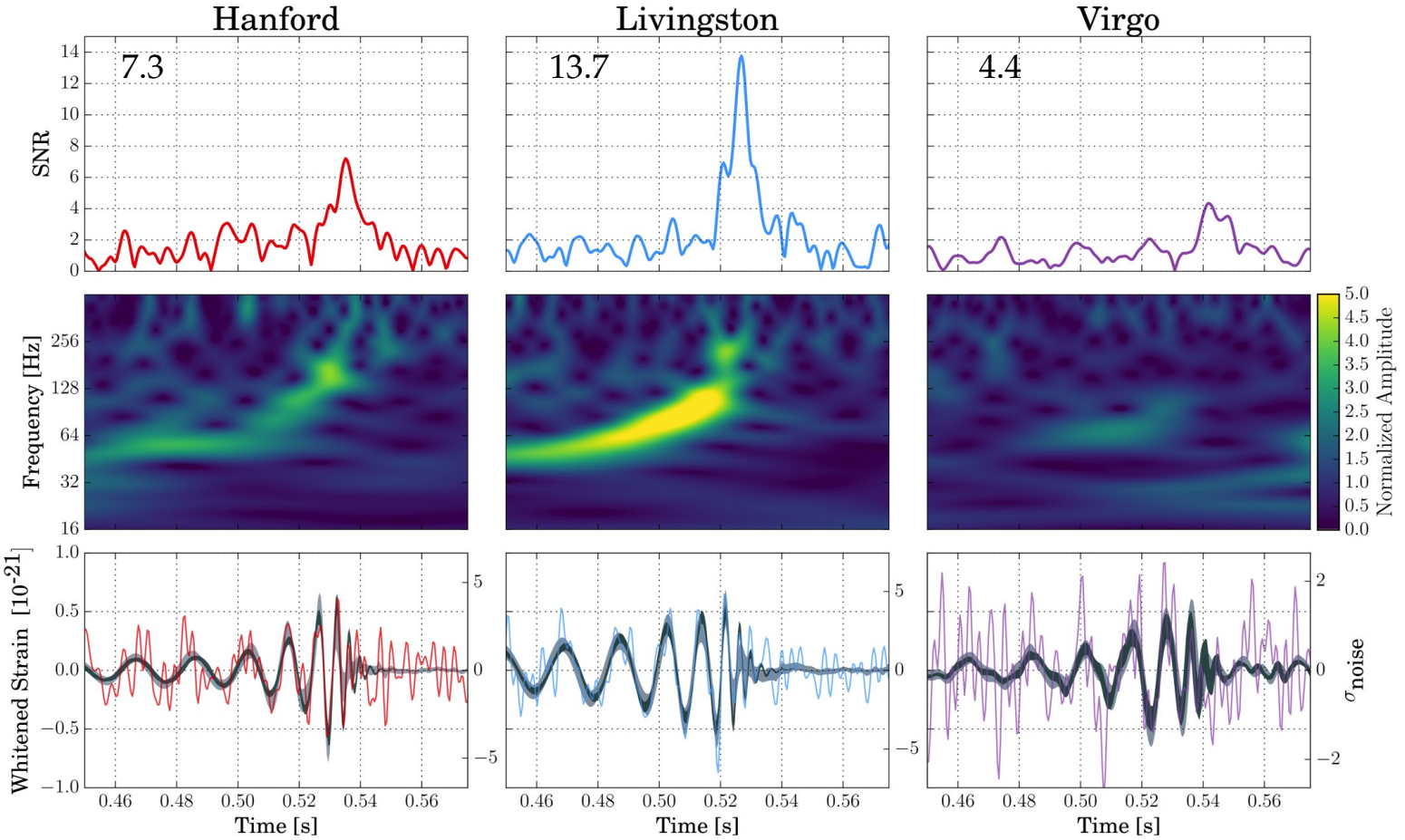
Advanced Virgo sensitivity

- Advanced Virgo joined the Avanced LIGO interferometers on the O2 data taking the 1st of August until the 25th with *82.5% of duty cycle* and ~*26 Mpc of BNS range*



First detection: GW170814

- On August 14th a gravitational wave arrived at 10:30:43 UTC at Livingston, 8 ms later at Hanford and 14 ms later at Virgo
  - The presence of Virgo *reduced the error in the sky area* by a **factor 20**



BBH @ 540 Mpc

30 + 25 $M_\odot$ =

53 $M_\odot$