Sensing & Control of the Advanced Virgo experiment

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Gravitational Waves

- Perturbative wave-like solutions to Einstein's equations:

$$\mathbf{g} = \eta + \mathbf{h} \quad , \quad |h_{\mu\nu}| \ll 1 \quad \Longrightarrow \left(\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) h_{\mu\nu} = 0$$

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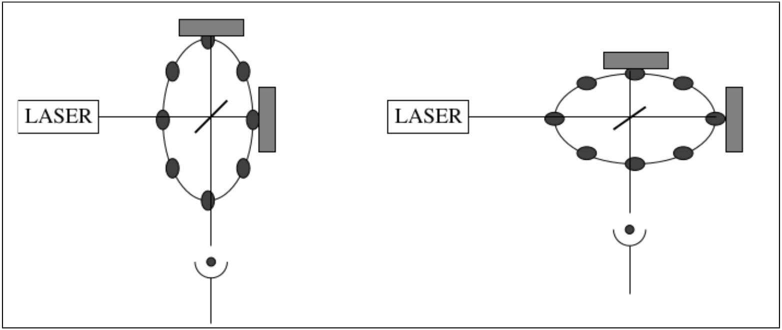
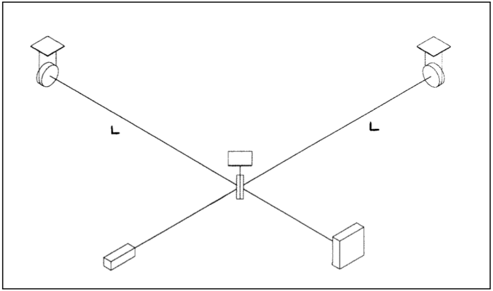
The amplitude we are looking for is extremely small!

GW Detection through Interferometry (1)



Effect of a GW on an interferometer

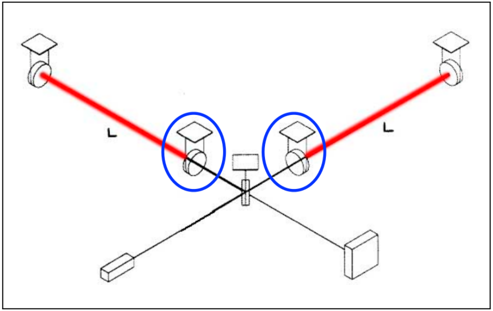
GW Detection through Interferometry (2)



Michelson Interferometer

- Detection based on ΔL between arms
- $\Delta L \approx \frac{1}{2} h L$
- From quadrupole approximation, $h \simeq 10^{-21}$
- If $L \simeq 10^{3}$ m we have to measure $\Delta L \approx 10^{-18}$ m !

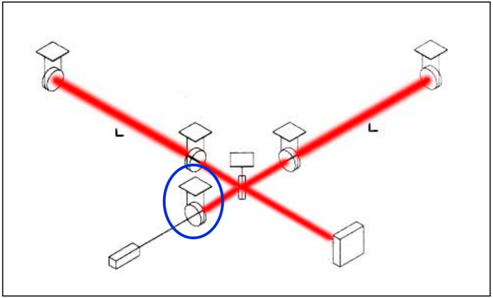
GW Detection through Interferometry (2)



Interferometer with Fabry-Pérot cavities

- ✓ Length-to-phase transduction is amplified:
  - Effective length $L' = L \cdot \frac{2\mathcal{F}}{\pi}$
  - Finesse: $\mathcal{F} = \frac{\pi R}{1-R}$
  - Maximised *phase response*
- ⊗ Drawback: requires a *resonant condition* to work

GW Detection through Interferometry (2)

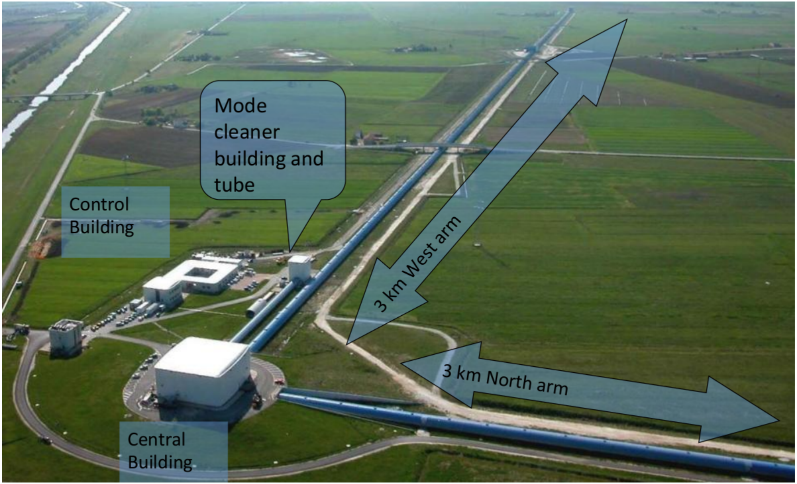


Power-Recycled configuration

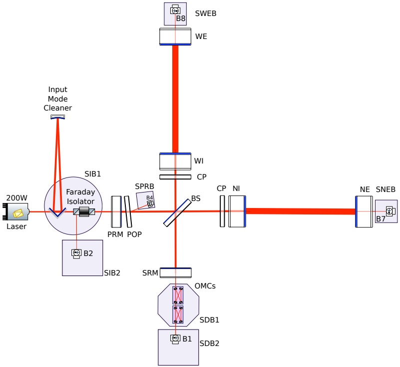
The idea is to *recycle* the wasted light:

- ✓ $P_{\text{eff}} \gg P_{\text{input}}$ (factor ~ 50)
- ✓ Shot Noise reduced (factor ~ 7)
- ⊗ Another resonant cavity to be controlled

The Virgo Experiment



The 2nd generation: Advanced Virgo (1)



- 200 W laser
- Larger beam
- New optical layout
- Heavier mirrors
- Increased Finesse
- Upgraded Superattenuator
- *Signal Recycling* cavity

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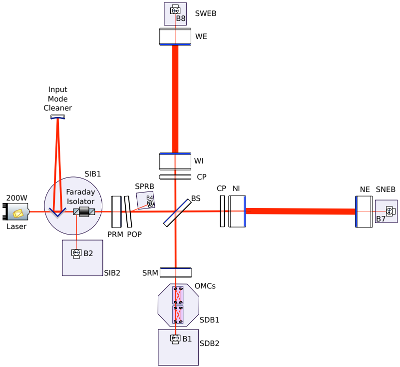

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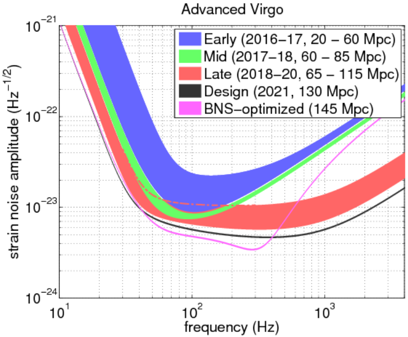
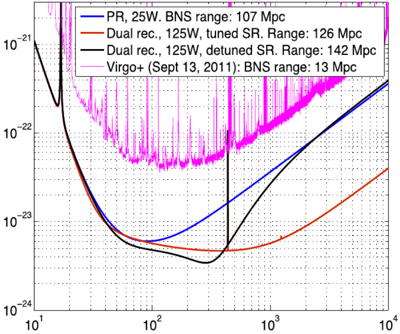
Developing a new Lock Acquisition scheme is mandatory!

The 2nd generation: Advanced Virgo (2)

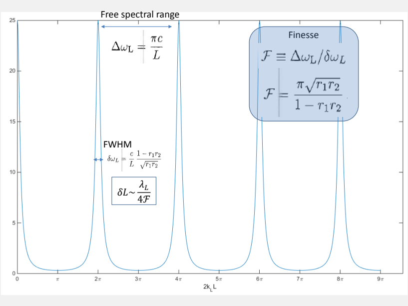


Sensitivity: evolution in time



Sensitivity: different configurations

Operation Conditions



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- Error signals only valid at the *nanometer* scale
- Working accuracy is at the picometer scale

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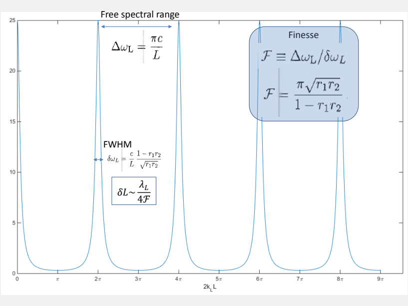

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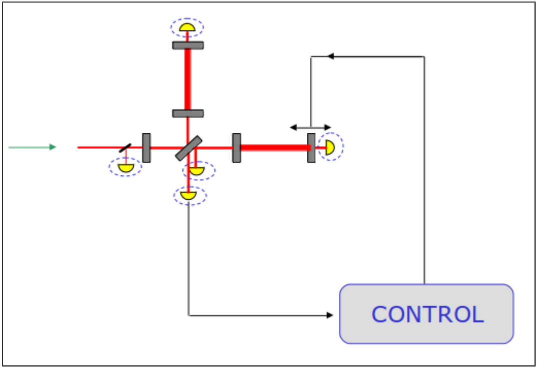
⇓

This requires a complicated procedure known as Lock Acquisition

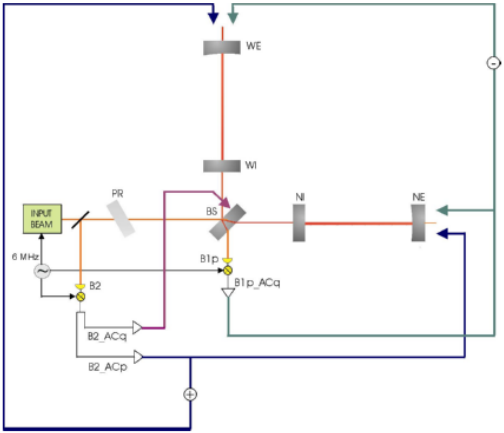
Lock Acquisition

- Error signals are available only *around resonance*
- Error signals are extracted at the output ports
- Error signals are used to compute correction signals
- Correction signals are sent to the optics



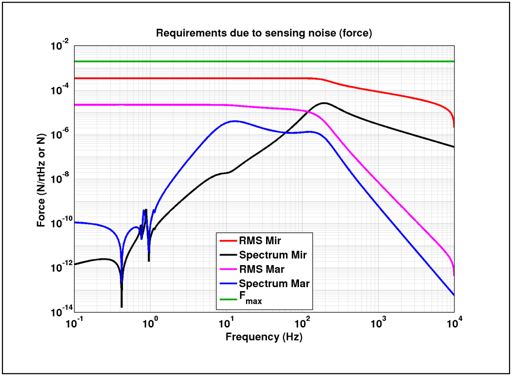
Lock Acquisition

- Once the ITF is locked on its operating point, the control scheme is optimized in order to reduce the control noise
- Use of less noisy error signals
- Use of more aggressive filters



Simulations: requirements on actuation force

Study of the sensing noise and impact on actuators:



Electronic noise's impact vs. Force

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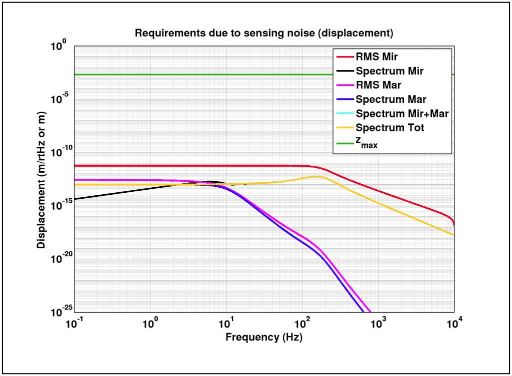
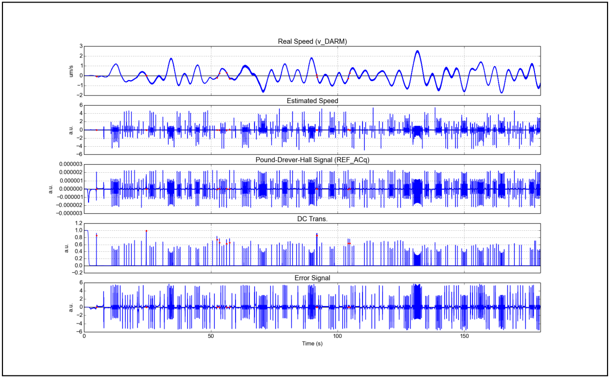


Electronic noise's impact vs. Displacement

Simulations: the *Guided Lock* algorithm (1)

Evaluation of residual cavity velocity via optical signals:



Simulation of freely swinging cavity

Simulations: the *Guided Lock* algorithm (1)

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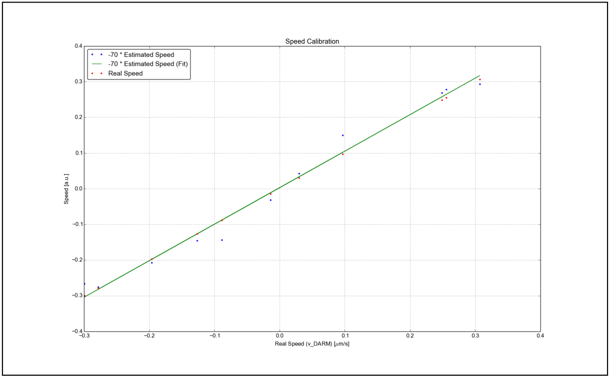
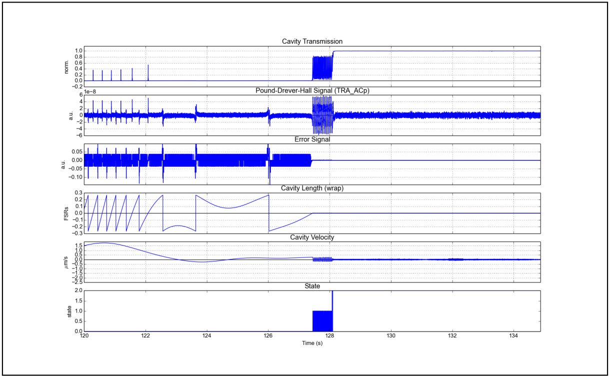


Error Signal vs. Cavity Velocity

Simulations: the *Guided Lock* algorithm (2)

Single impulse to reduce velocity & lock with transmission signal



Transmission lock of arm cavity (1)

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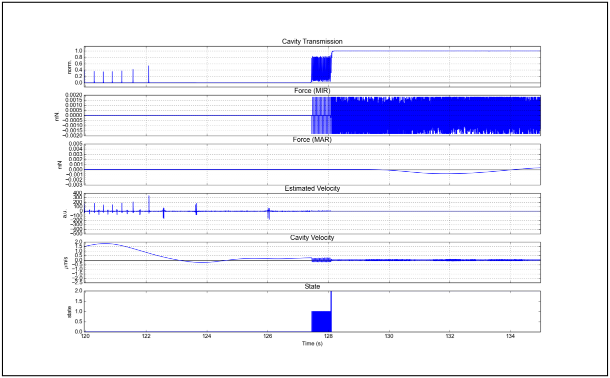

Transmission lock of arm cavity (2)

Conclusions

- The experimental apparatus is undergoing a significant update
- New challenges due to stricter operating conditions
- Efforts ongoing into characterization, simulations and development:
  - study of the new actuators
  - simulations of the new arm cavities
  - development of a new lock acquisition strategy

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2016 is the year of Advanced Virgo