Interferometer Sensing and Control

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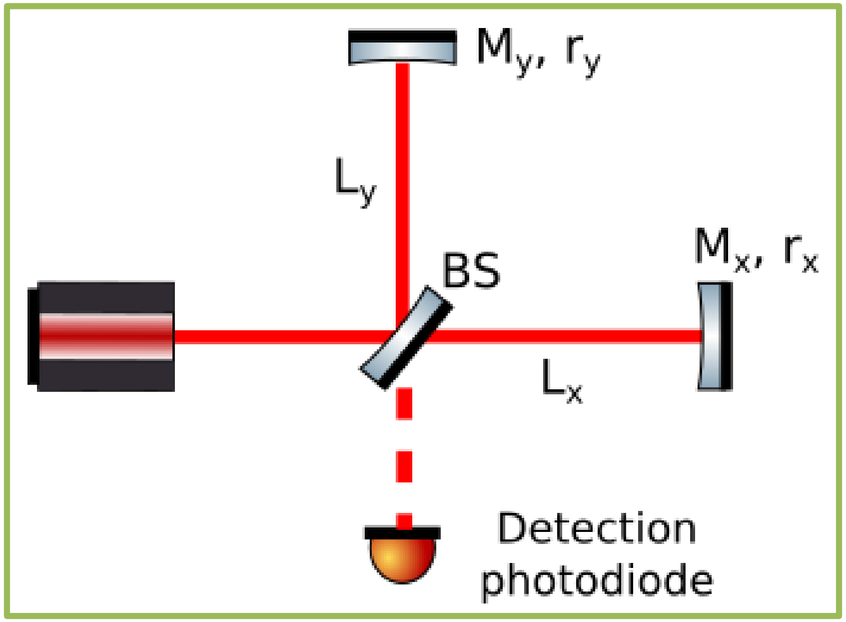
Detection principle

- Differential effect → **Michelson interferometer**
- Free test masses → **Suspended mirrors**

Interference depends on the phase difference between the Michelson arms→ *<u>sensitive to length difference</u>*

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

Michelson interferometer



Change on the detected power

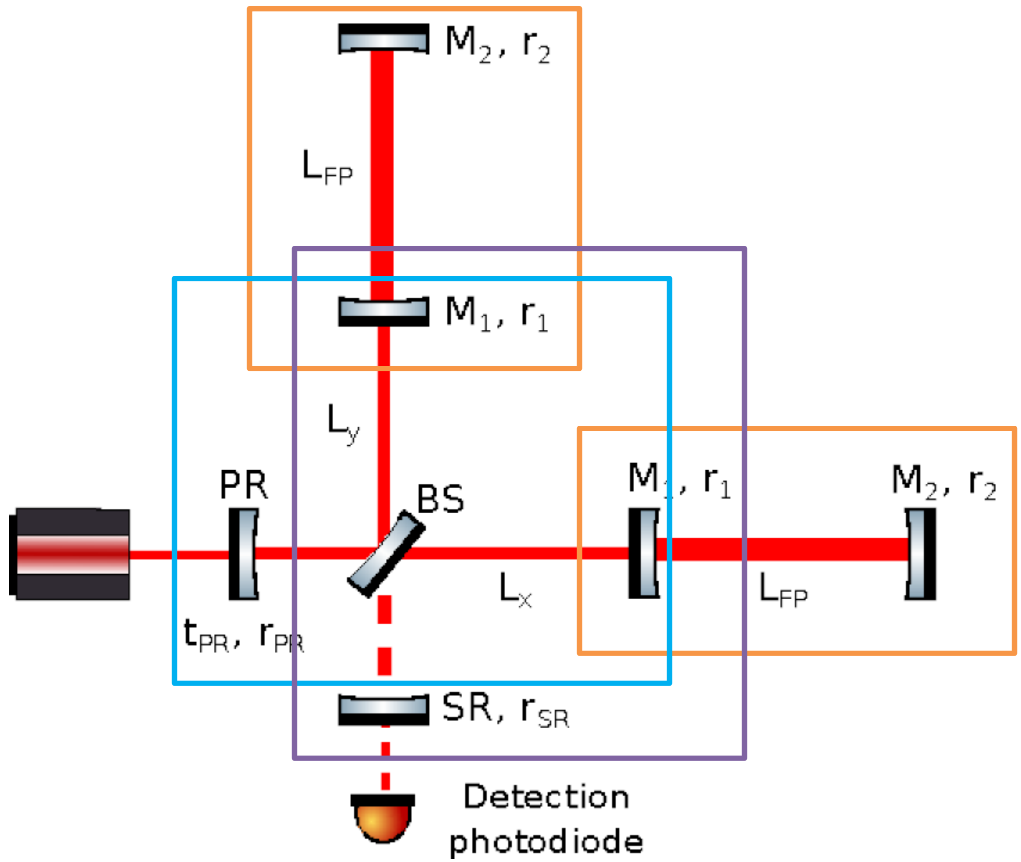
δP_{det}

Optical Layout

Target: reach the **maximal sensitivity** → *maximize the SNR* at the detection photodiode

Michelson → ***Dark Fringe***

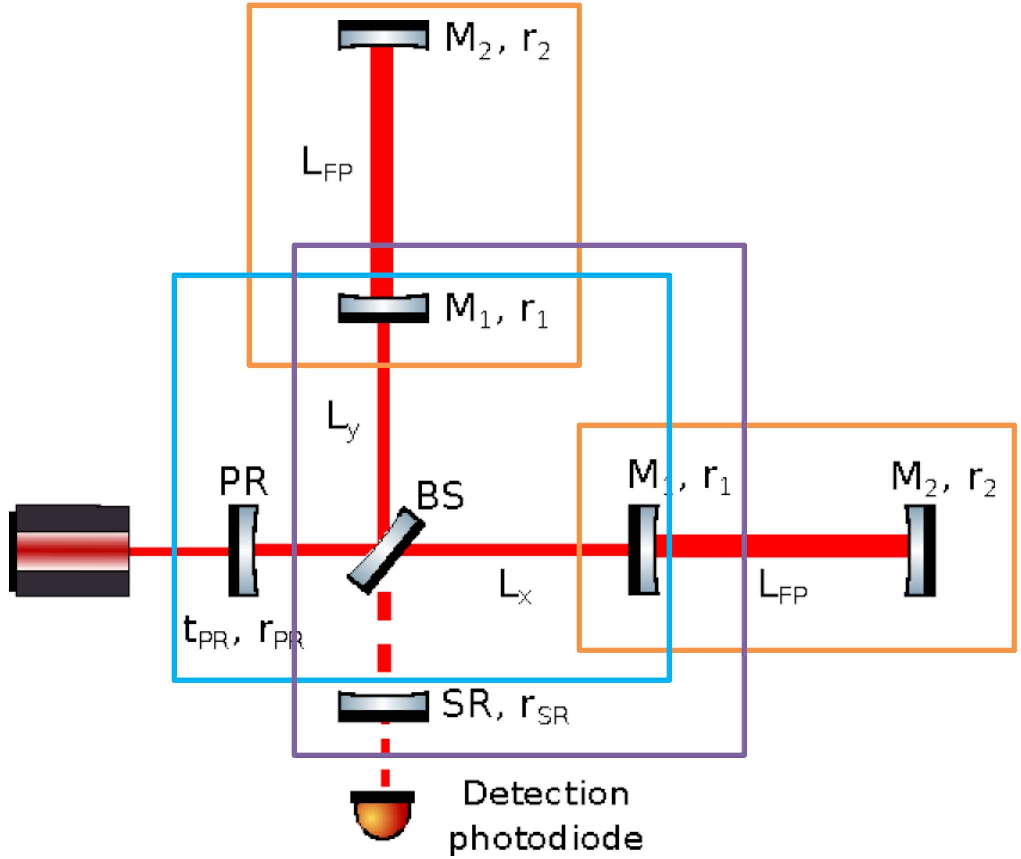
Not enough to reach the expected sensitivity **$h < 10^{-21}$**



Optical Layout

Target: reach the **maximal sensitivity** → *maximize the SNR* at the detection photodiode

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



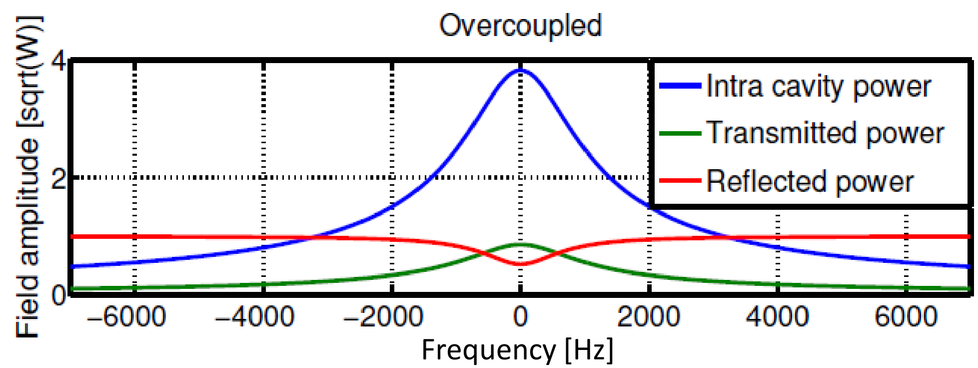
IMPROVEMENTS:

1) **Fabry-Perot cavities in the arms of the Michelson (3 km)** → increase the optical path
2) **Power Recycling Cavity** → increases the effective input power
3) **Signal Recycling Cavity** → recycles the gravitational waves signals

4 Optical cavities **suspended and coupled**

Working point

- Optical cavity: allows light to circulate in a closed path
- **Resonance:** maximum power resonating inside the cavity
- **Optical Gain:** quantifies the quality factor of the cavity



Arm Cavities OG ~ 300
Power Recycling Cavity OG ~ 40
Signal Recycling Cavity OG ~ 12

Working point of maximum sensitivity:

- Arm cavities, PRC and SRC → ***Resonance***
- Michelson → ***Dark Fringe***

Interferometer Sensing and Control

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→ working point of each DOF is crossed in a random way

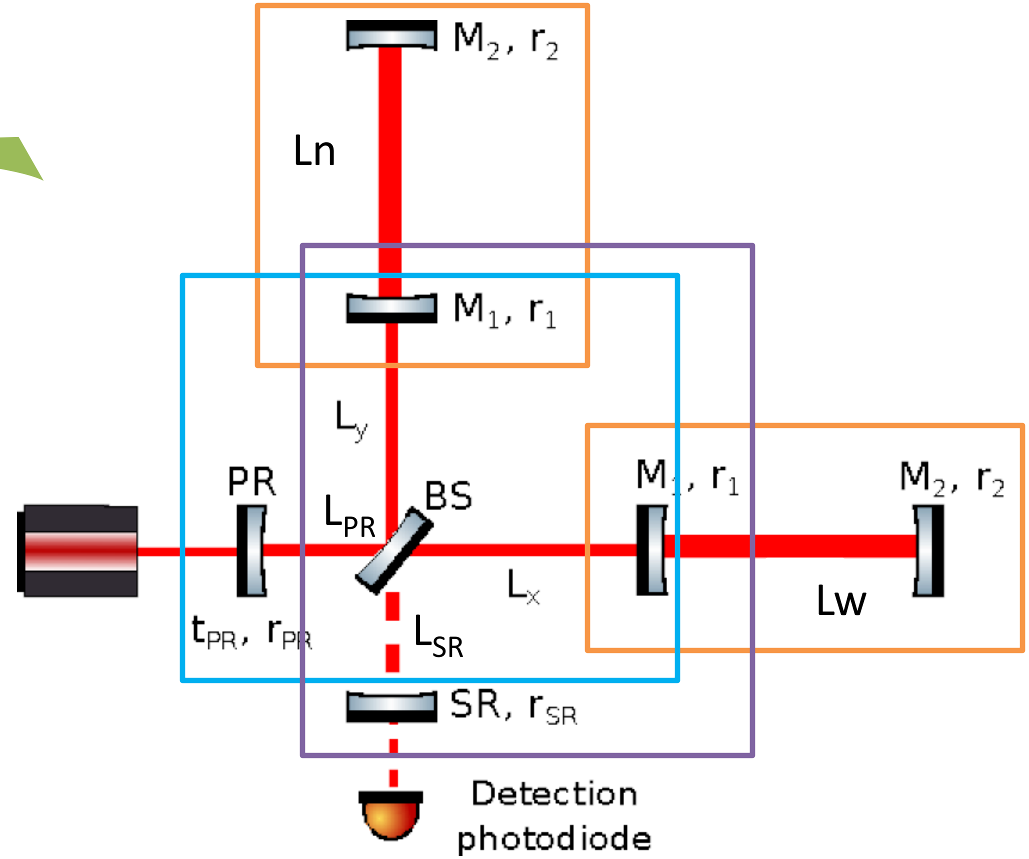
→ **Active control** is necessary to keep the ITF at its working point

- → Information about the mirror movement: optical sensors
- → Digital processing of this information in real time
- → Actuate on the suspensions accordingly

Longitudinal DOFs

5 Longitudinal Degrees Of Freedom:

- MICH: Lx – Ly
- PRCL: L_{PR} + (Lx + Ly) / 2
- SRCL: L_{SR} + (Lx + Ly) / 2
- CARM: Ln + Lw / 2
- **DARM: Ln - Lw / 2**



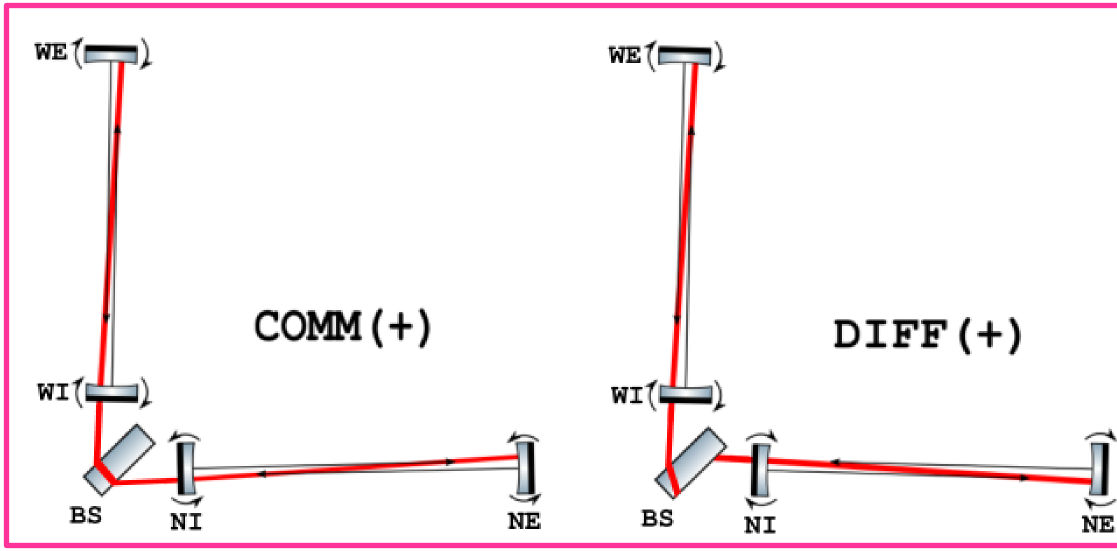
From these definition we can estimate the maximum residual motion of each DOF not to spoil the sensitivity

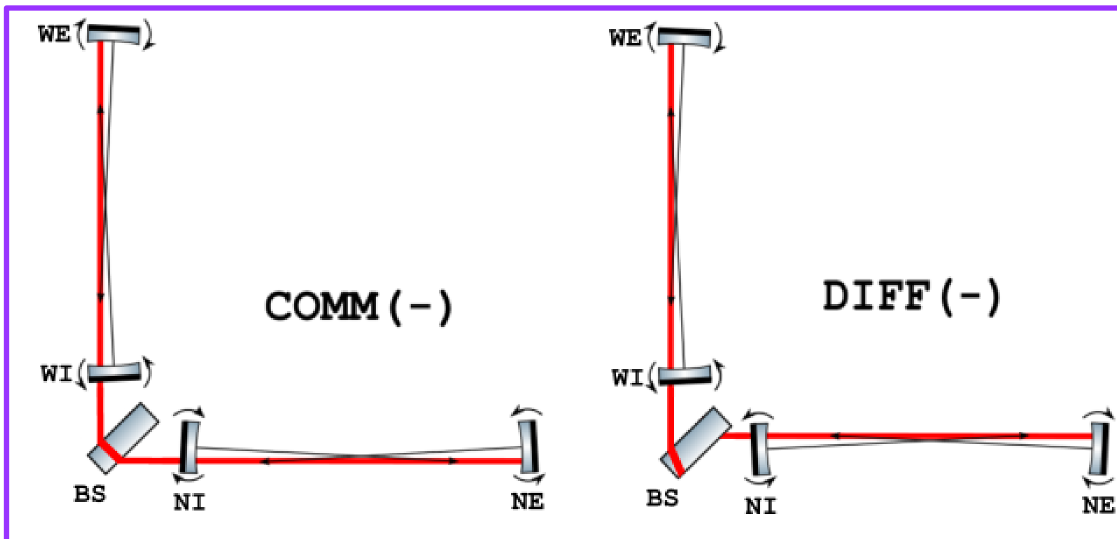
- → CARM ~ $4 \cdot 10^{-14}$ m
- → DARM ~ $6 \cdot 10^{-12}$ m
- → MICH ~ $2 \cdot 10^{-9}$ m
- → PRCL ~ $7 \cdot 10^{-11}$ m
- → SRCL ~ $2 \cdot 10^{-10}$ m

Angular DOFs

→ There are (*6 mirror angular DOFs* **+** *2 input beam angular DOFs)* **x** *2 symmetry planes* **= 16 DOFs in total**

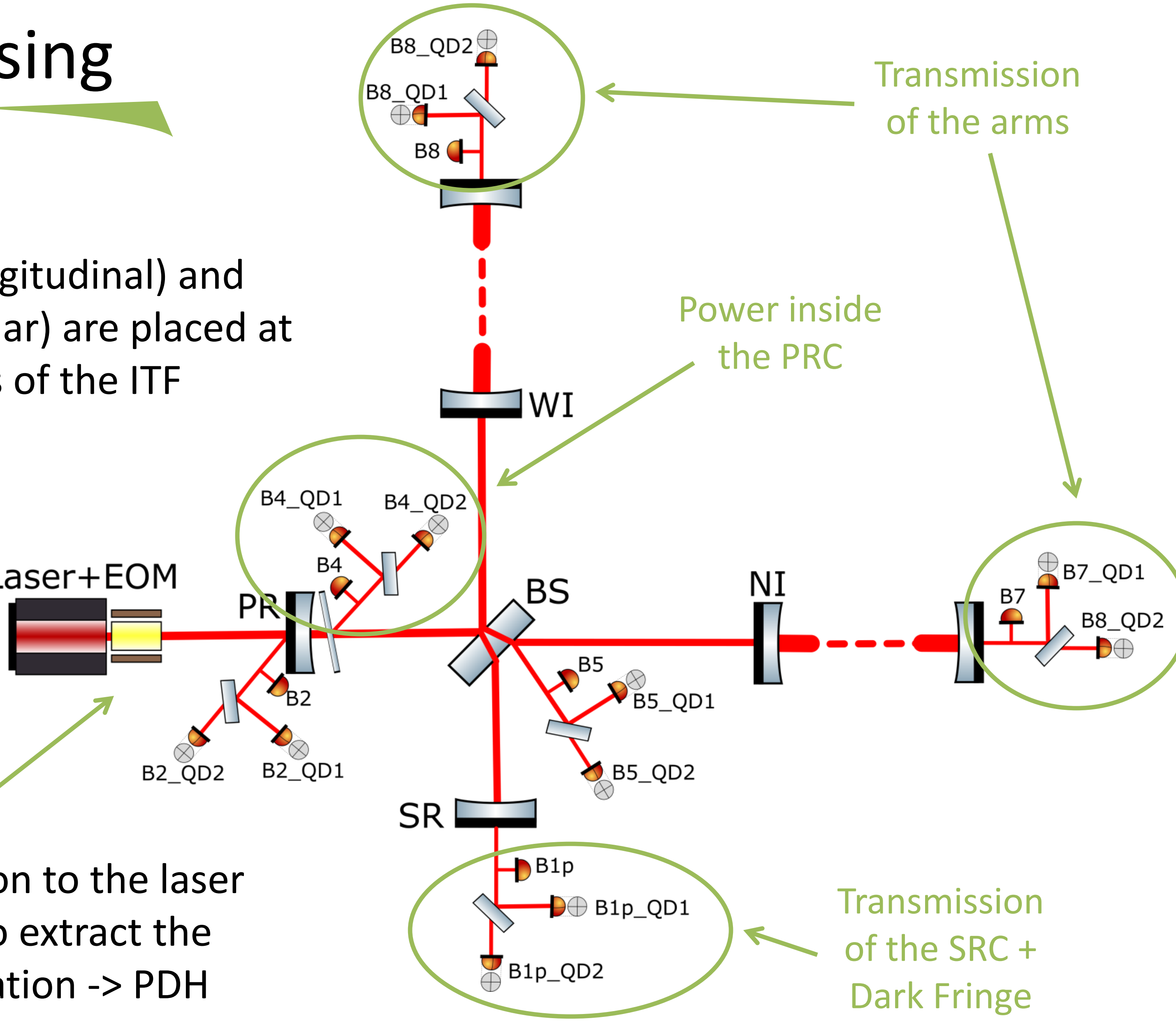
- **BS** mirror tilt
- **PR** mirror tilt
- Cavities tilt **(+)**: **Comm** and **Diff**
- Cavities shift **(-)**: **Comm** and **Diff**





Optical sensing

- Photodiodes (longitudinal) and Quadrants (angular) are placed at the critical points of the ITF



- Phase modulation to the laser source is used to extract the relevant information -> PDH technique

Error signals

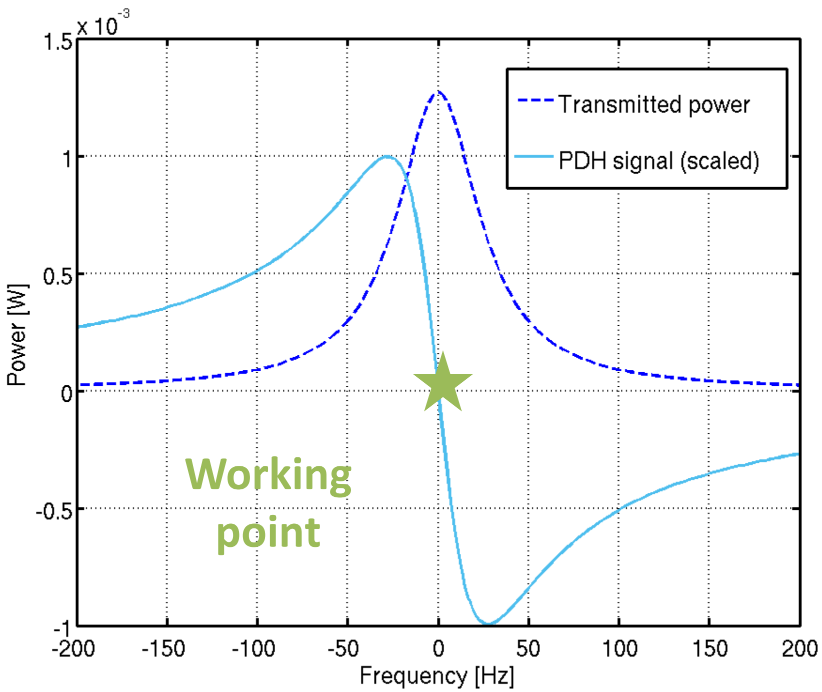
→ **Error signal:** provides information about how far is the cavity length from the resonance position

→ We need to extract information about the *laser phase*

→ **Phase modulation**: create *sidebands* around the carrier (ω_0) at $\pm$ the modulation frequency, Ω.

→ The modulation frequencies are chosen to be anti-resonant → *act as a reference*

→ **Error signal** → *beat note between carrier and non-resonant sidebands*



Control strategy

→ The DOFs are *very coupled* due to the Recycling Cavities and their *working point is crossed randomly* → their control *can not be engaged simultaneously*

→ Try to simplify the optical configuration by *removing degrees of freedom*

→ The addition of the SR mirror forced us to implement a new *control strategy based on the use of Auxiliary Lasers*

Auxiliary Lasers

Auxiliary Lasers -> *a pick-off of the main laser*, propagated through an optical fiber 3kms and then doubled in frequency in the terminal buildings (green light!)

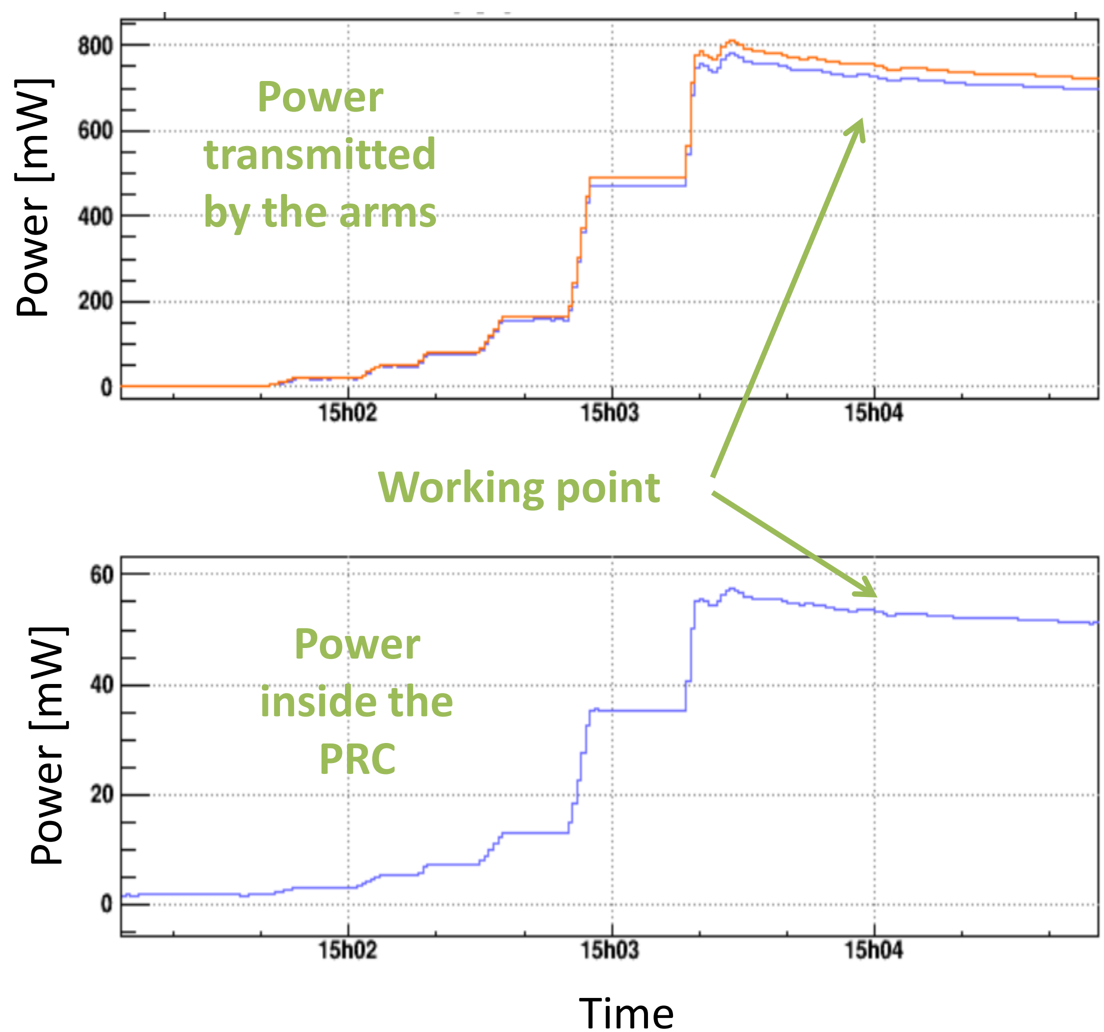
1. The Auxiliary Lasers allow to keep the arm cavities ***on resonance for the green*** but *far from resonance for the main laser* → this **"removes" 2 dofs**

2. The remaining dofs, the Central Interferometer: *MICH, PRCL, SRCL,* can be controlled **simultaneously**

3. At this point the 5 dofs are under control → *arms are brought to resonance for the main laser* → passing through intermediate stable states

Advanced Virgo +

- We are now able to bring the ITF from its free swinging state to the working point
  - It takes around 5 minutes
- The work now is focused on: *fine tuning the working point* and make the final state robust enough to *keep the ITF controlled during long stretches of time*



To be continued...