Experience with Signal-Recycling in GEO600

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Motivation

GEO600 is the 1st large scale GW detector using the advanced technology of Signal-Recycling:

- During commissioning of Dual-Recycling many (new) problems came up.

- Some problems are GEO specific, many are generally connected to the Signal-Recycling technique.

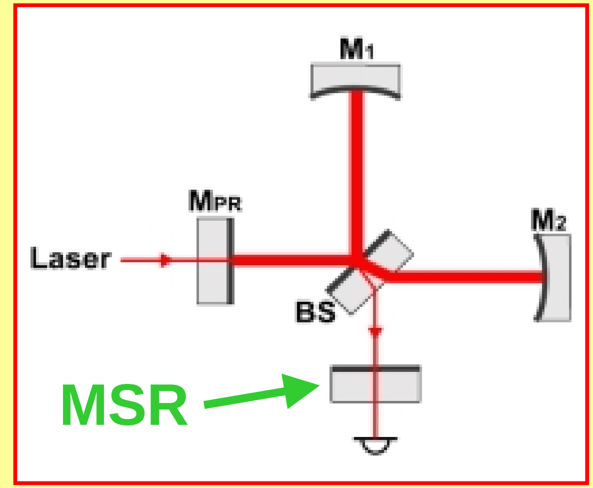
- We learned to cope with many of these new issues.

- Some of our experience is applicable to future detectors which may use Dual-Recycling.

Signal-Recycling in short

An additional recycling mirror (MSR) at the dark port allows:

- **enhancing the GW signal**
- **shaping the detector response**

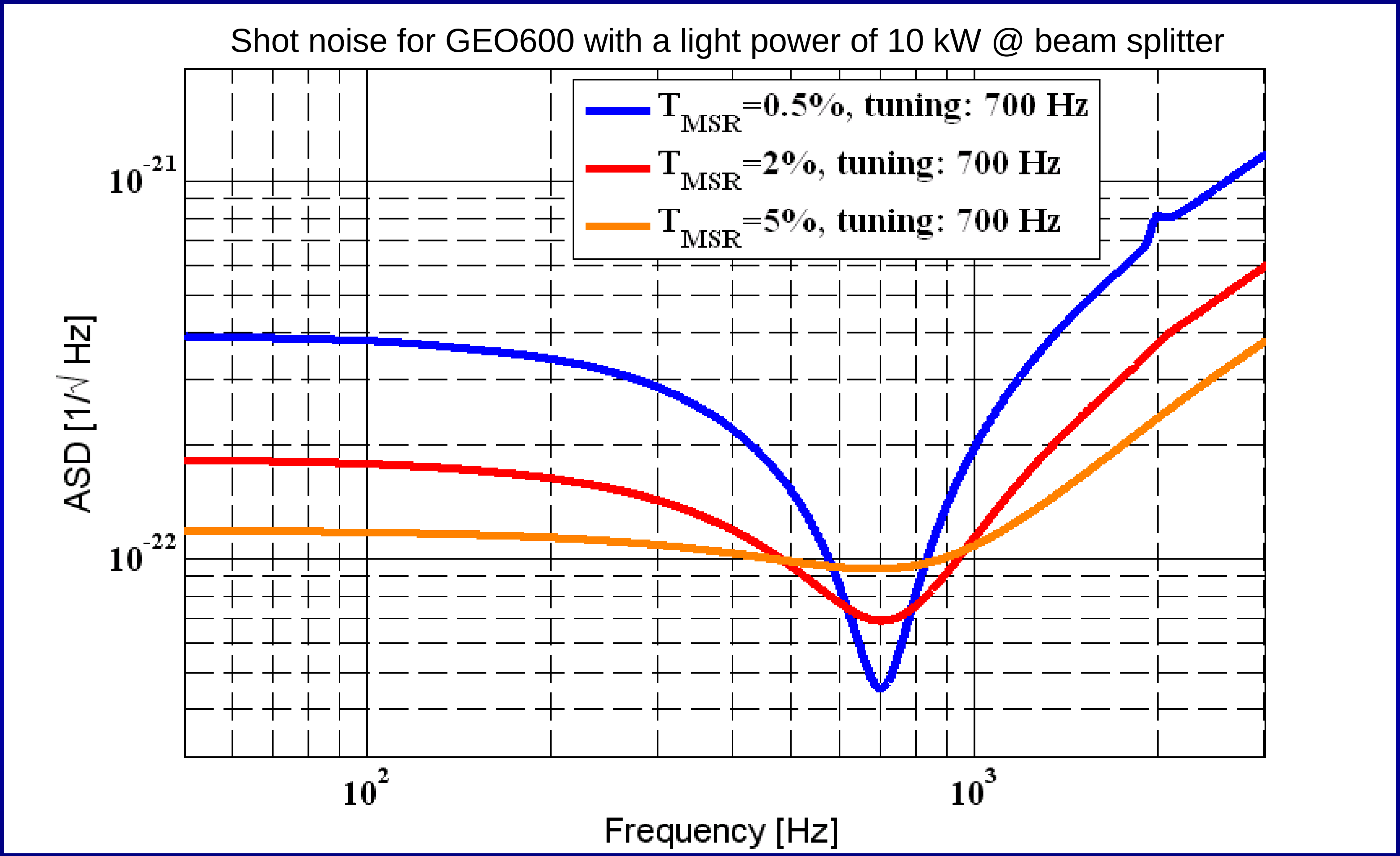


Two main parameters:

- **Bandwidth** (of the SR resonance) → broadband / narrowband
- **Tuning** (Fourier frequency of the SR resonance) → tuned / detuned

Shaping shot noise

Bandwidth of Signal-Recycling

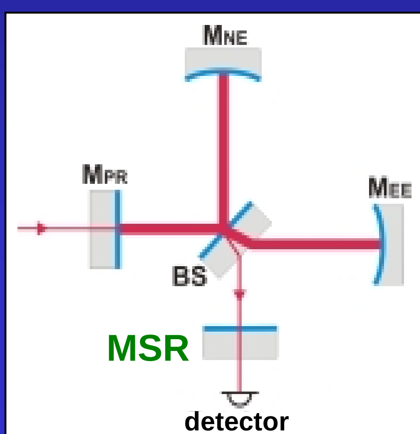


The bandwidth of the Signal-Recycling resonance is determined by the reflectivity of MSR.

Concepts for a variable bandwidth MSR

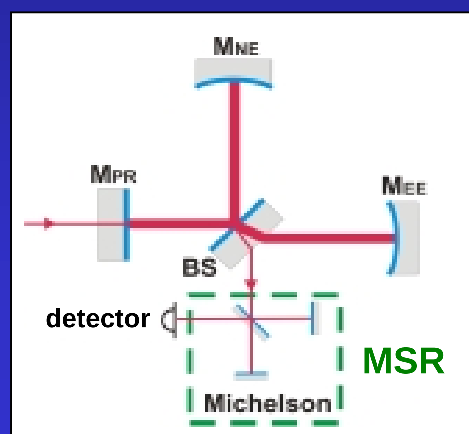
„Jukebox“

- Use several conventional mirrors
- Time-consuming
- Long detctor downtimes



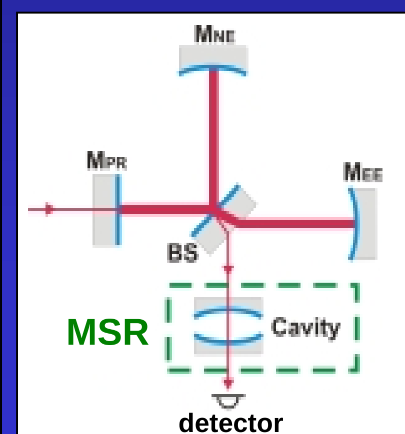
Michelson Interferometer

- SR-tuning by common-mode
- SR-bandwidth by differential-mode



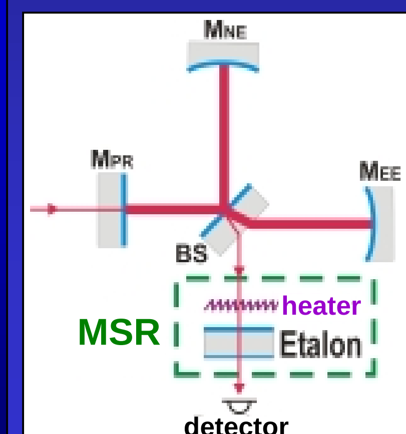
Cavity

- SR-tuning by common-mode
- SR-bandwidth by differential-mode

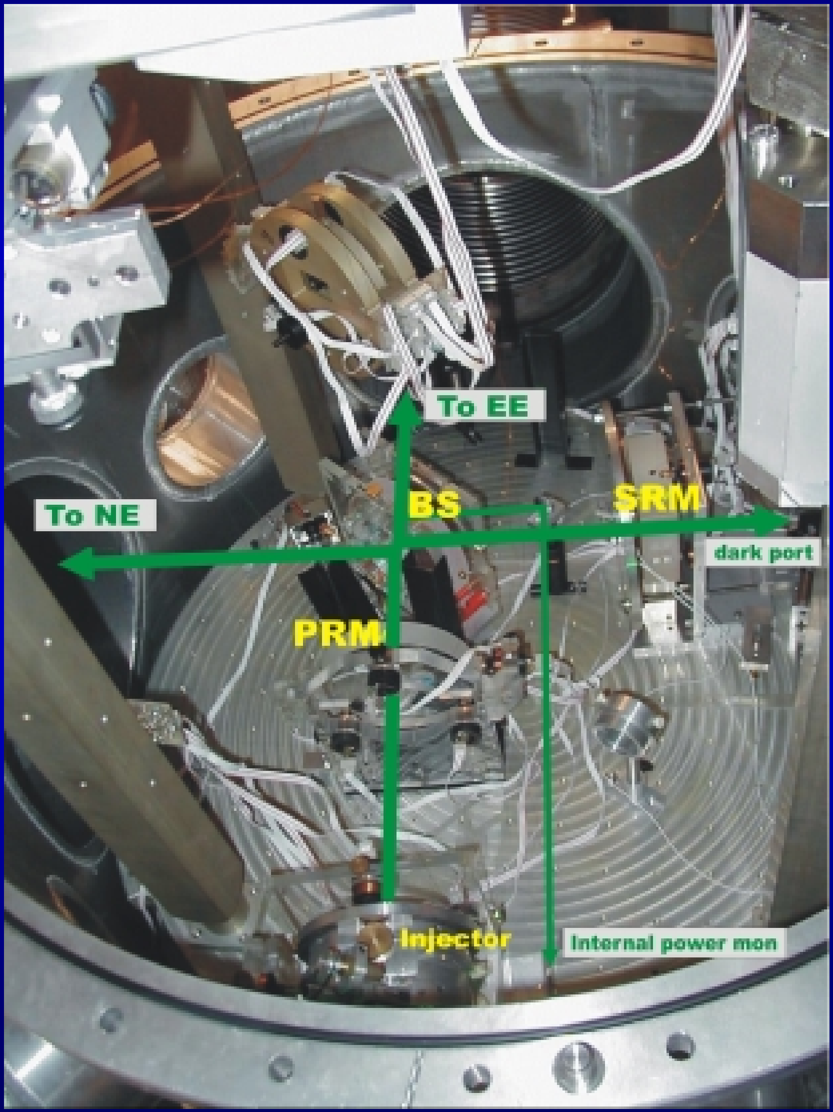


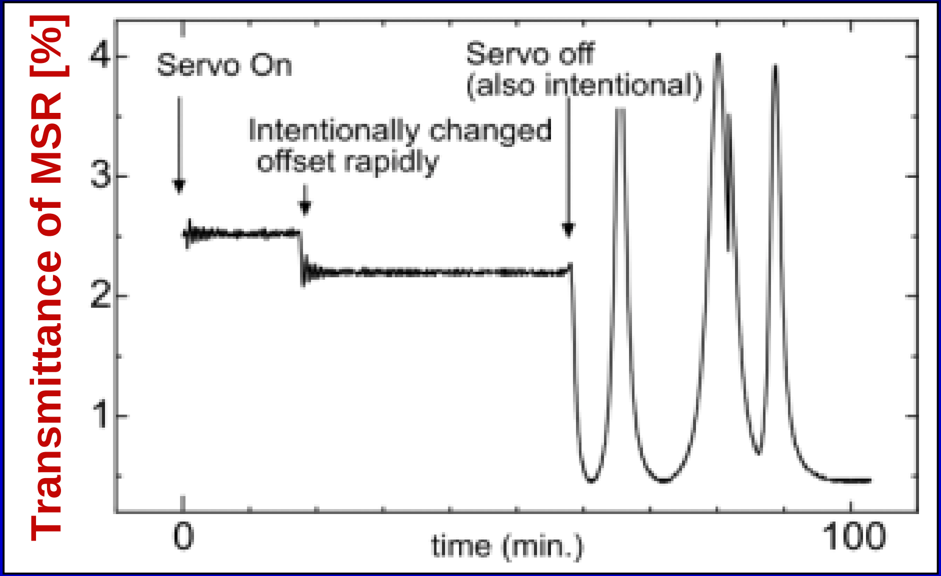
Etalon

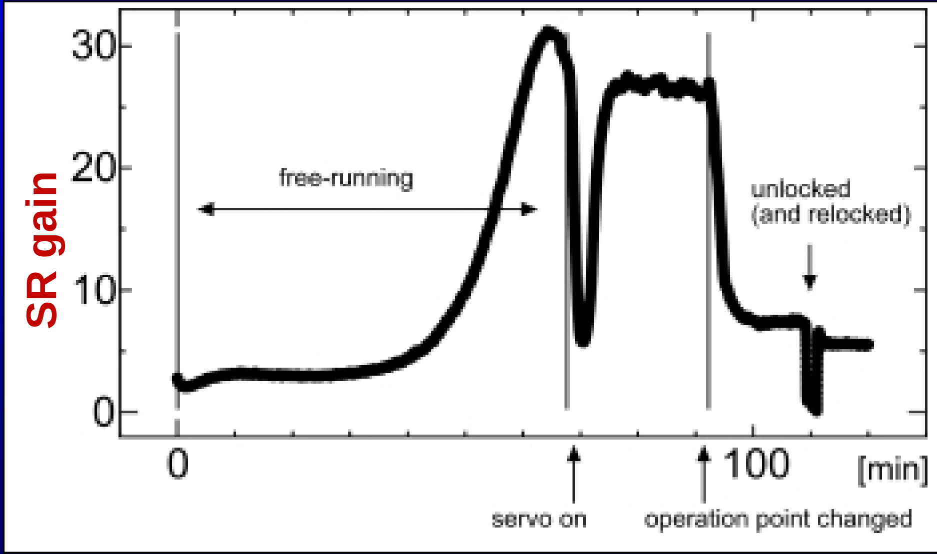
- SR-tuning by microscopic position of Etalon
- SR-bandwidth by temperature



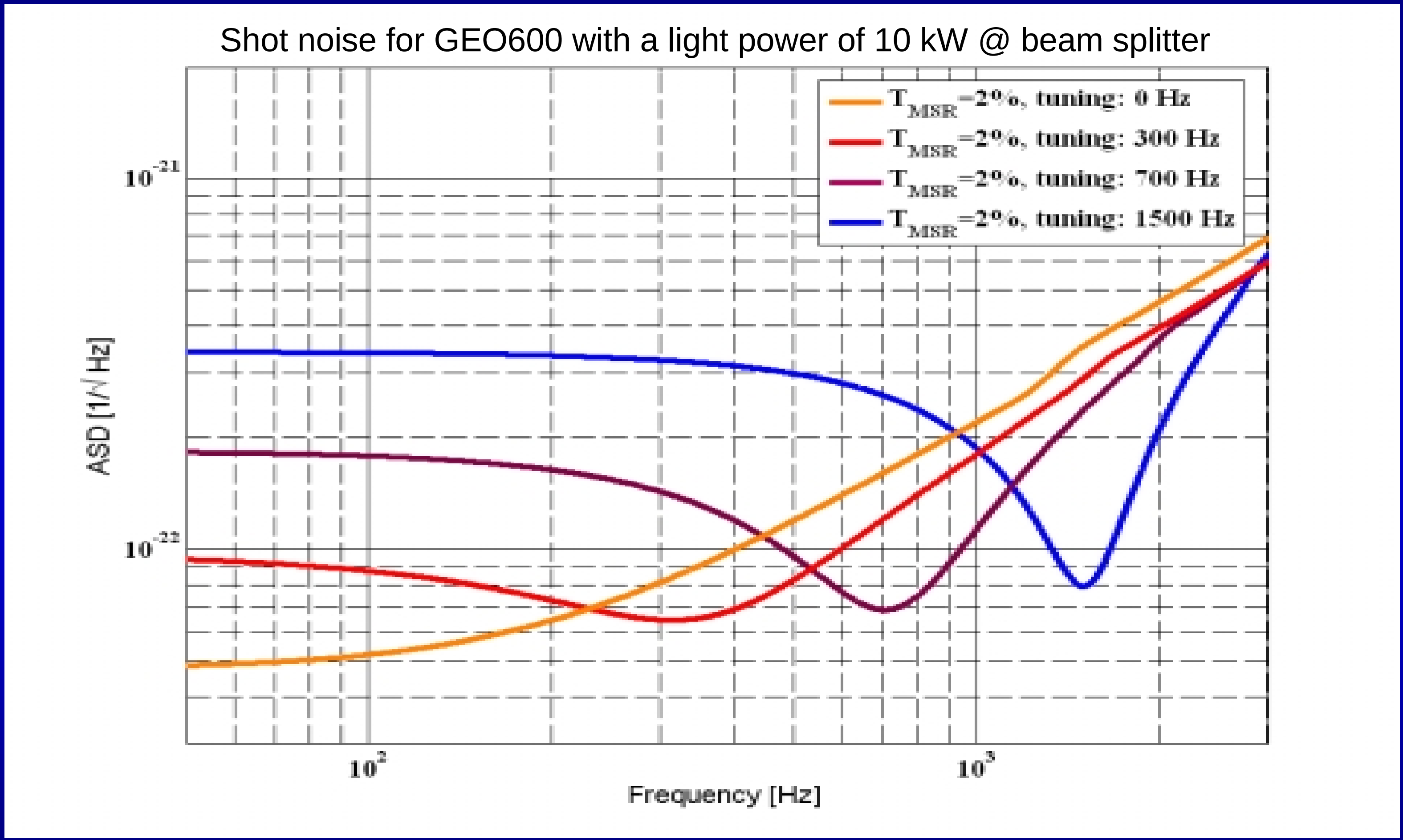
Demonstration of thermally tunable SR at Garching-Prototype (Keita Kawabe et al, 2003)







Tuning of Signal-Recycling



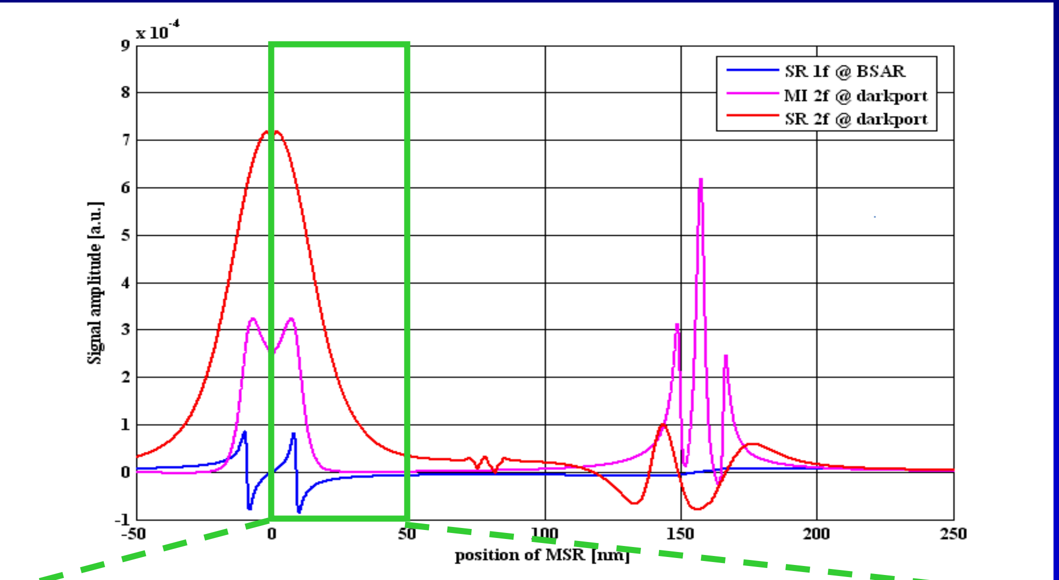
The tuning of the Signal-Recycling resonance is determined by the microscopic position of MSR.

Locking and tuning

Lock acquisition in GEO600

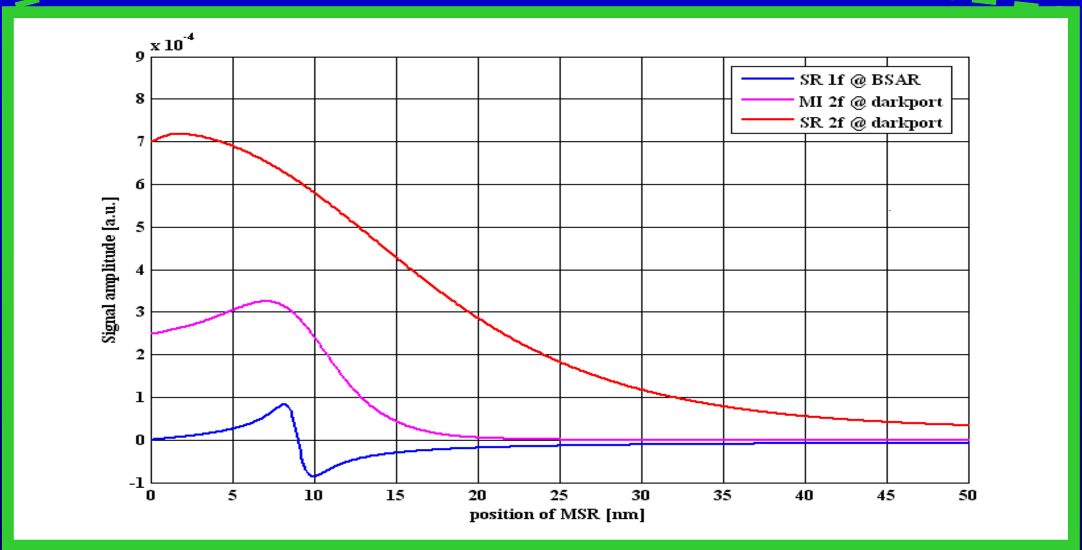
<u>Can't use the SR sideband (SR 1f) signal for initial lock:</u>

- strong dependence on varoius parameters (alignment, dark fringe offset)
- small capture range

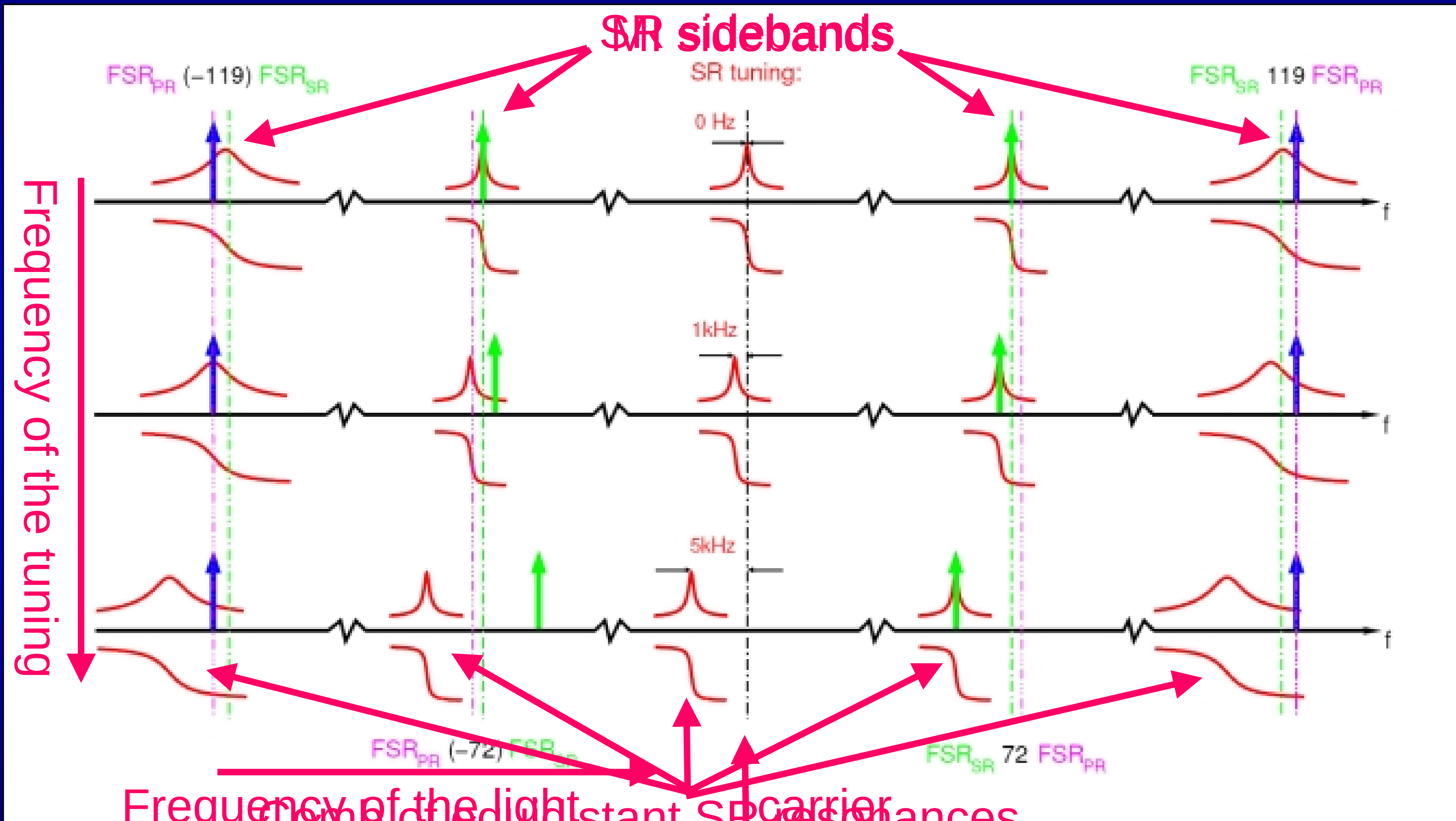


<u>Actual procedure:</u>

1. Locking to SR 2f at a detuning of 2.2 kHz
2. Switching to MI 2f
3. Switching to the SR sideband signal
4. Tuning the detector in small steps to its operation point.



Sideband picture (RF sidebands in SR cavity)



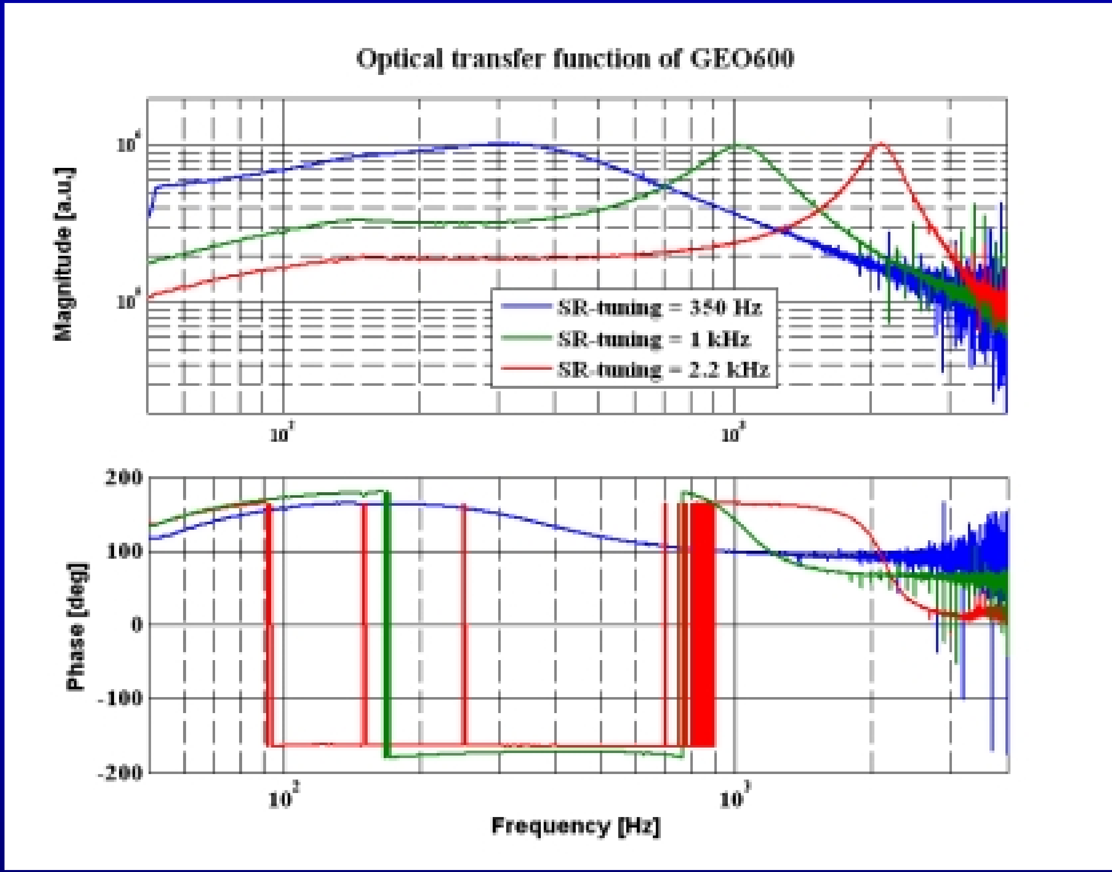
Some sidebands see resonances during downtuning.

Downtuning / Optical transfer function

Downtuning: About 70 steps of each 25 Hz (every 400ms)

<u>6 Parameters need to be adjusted:</u>

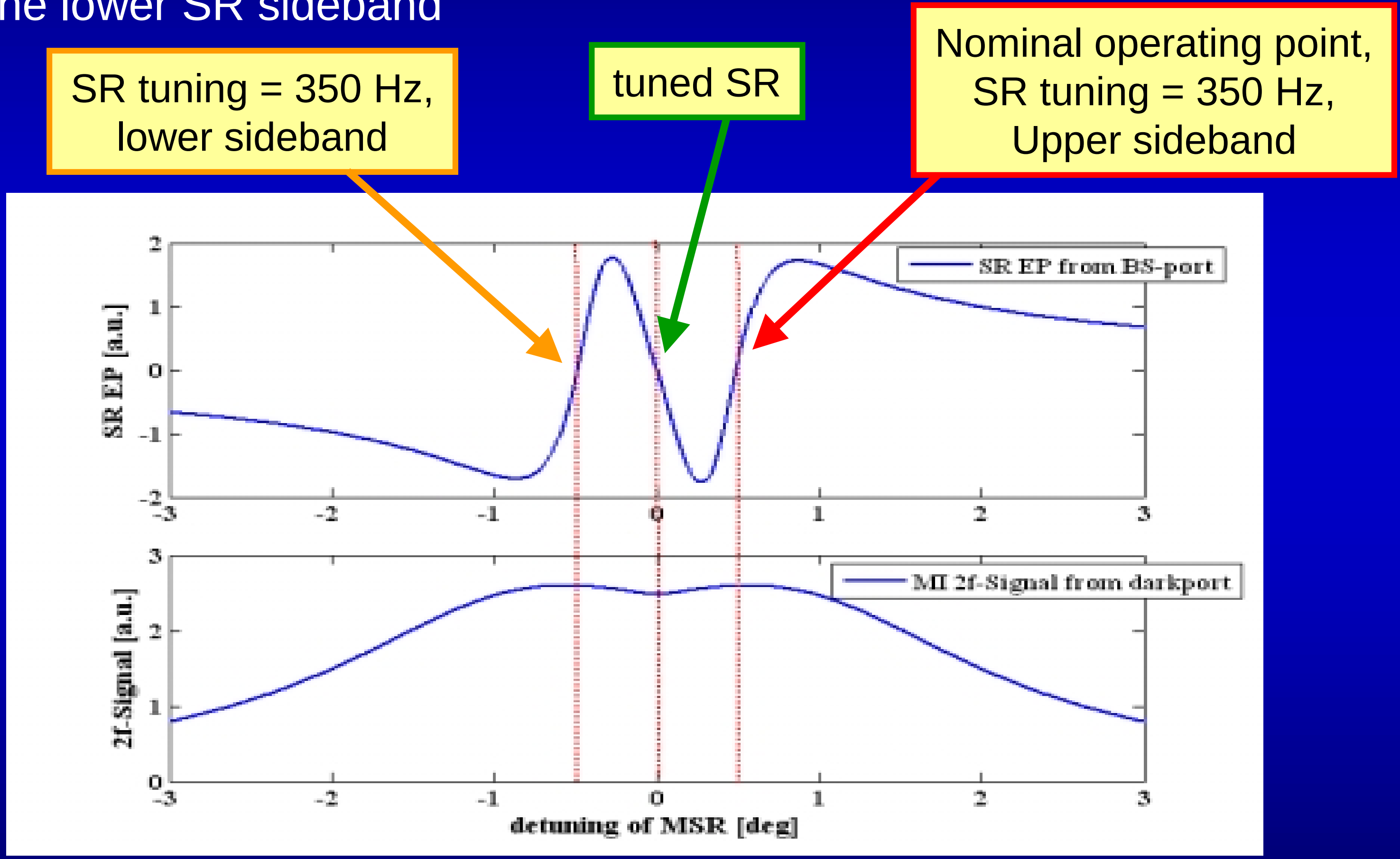
- SR frequency
- SR gain
- SR phase
- MI gain
- MI phase
- MI autoalignment gain



With this method we are able to tune SR to frequencies as low as 250 Hz.

Jumping to the lower SR sideband and to tuned Signal-Recycling

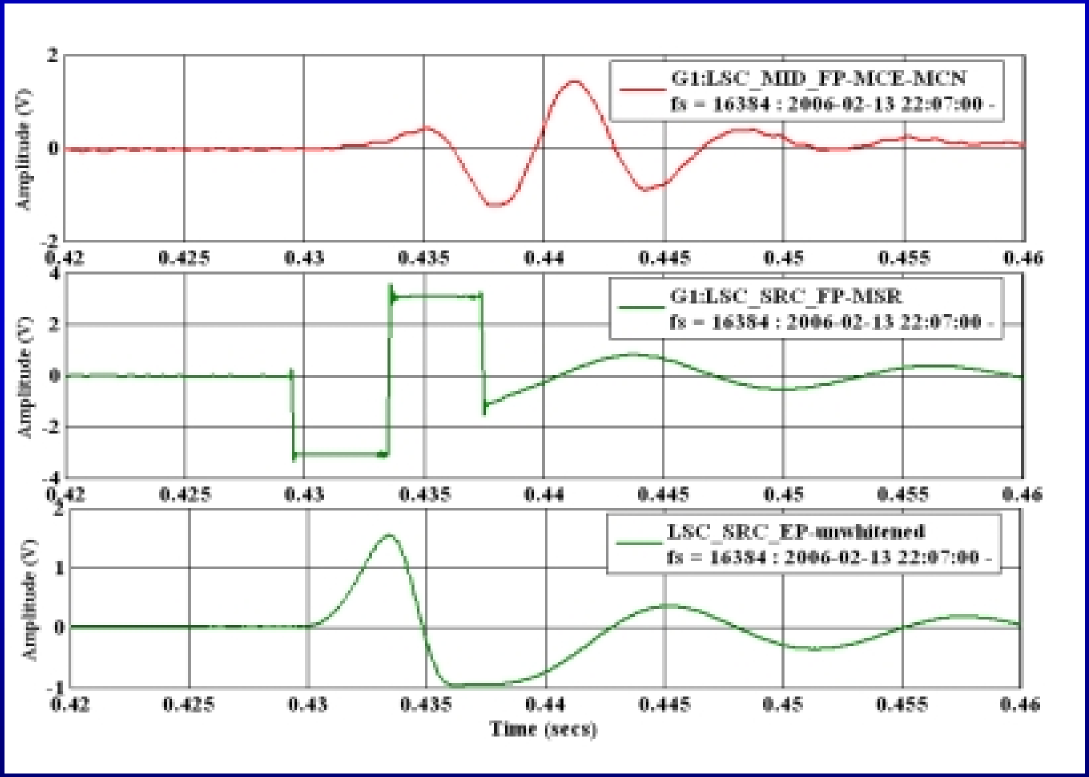
For various reasons we are not able to tune further down to the tuned case and then to the lower SR sideband



We can jump to the other sideband (only 2.8 nm for MSR) and to the tuned case (only 1.4 nm)

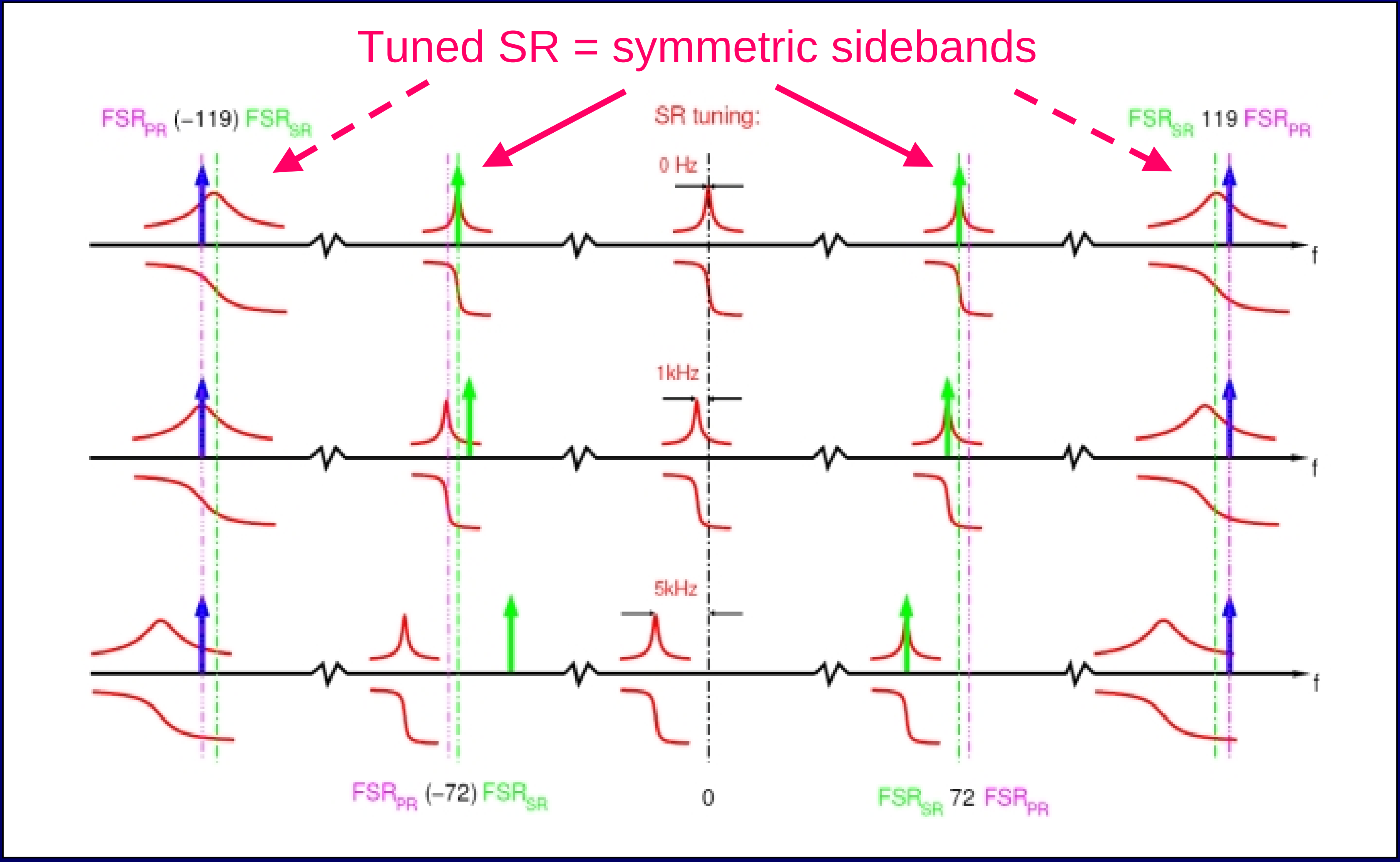
Kicking MSR

Kicking MSR in a controlled way:
- Fast enough that all other loops can‘t recognize.
- 4 ms of acceleration and 4 ms of deceleration.

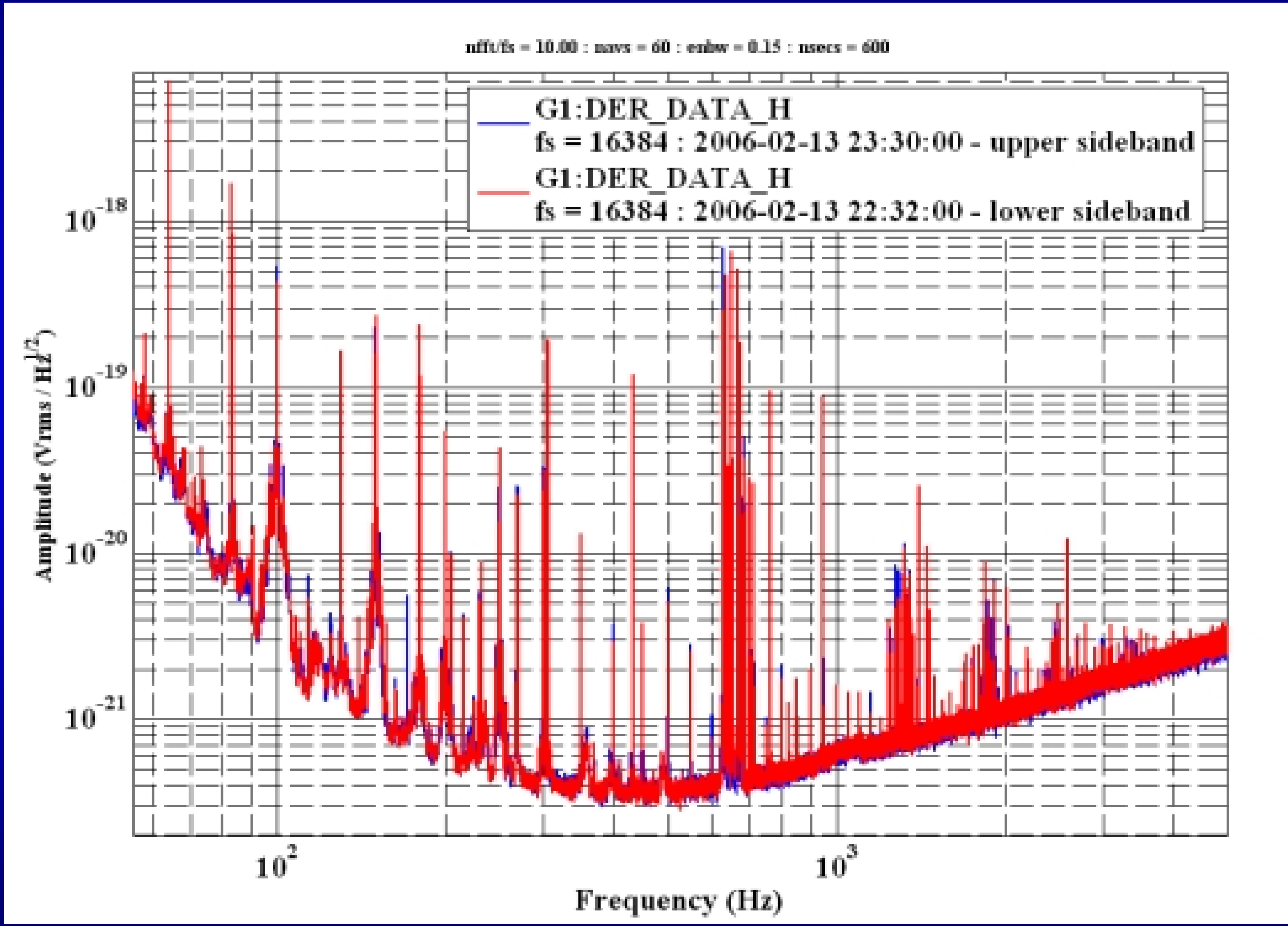


Works fine: Jumping to tuned and to the lower SR sideband

Sideband picture for tuned SR



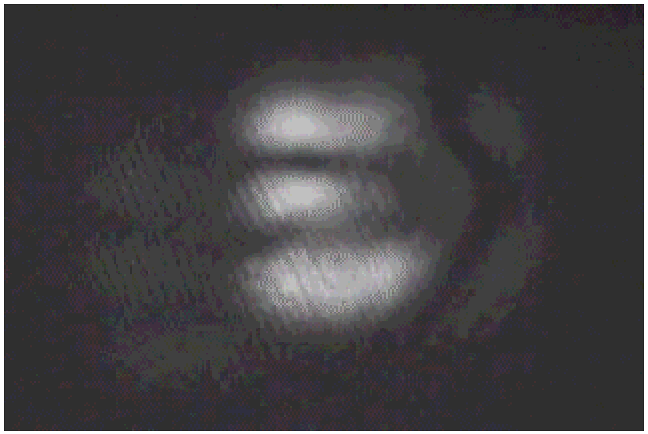
Sensitivity on different locking points



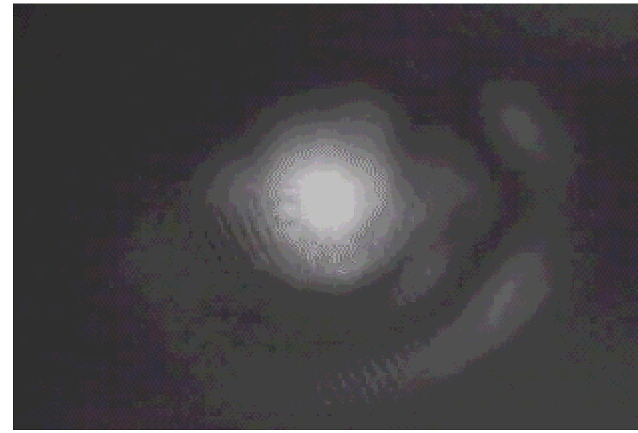
Sensitivity is identical for the two different locking points.

SR in operation

Mode healing



Power-Recycled Michelson



Dual-Recycled Michelson

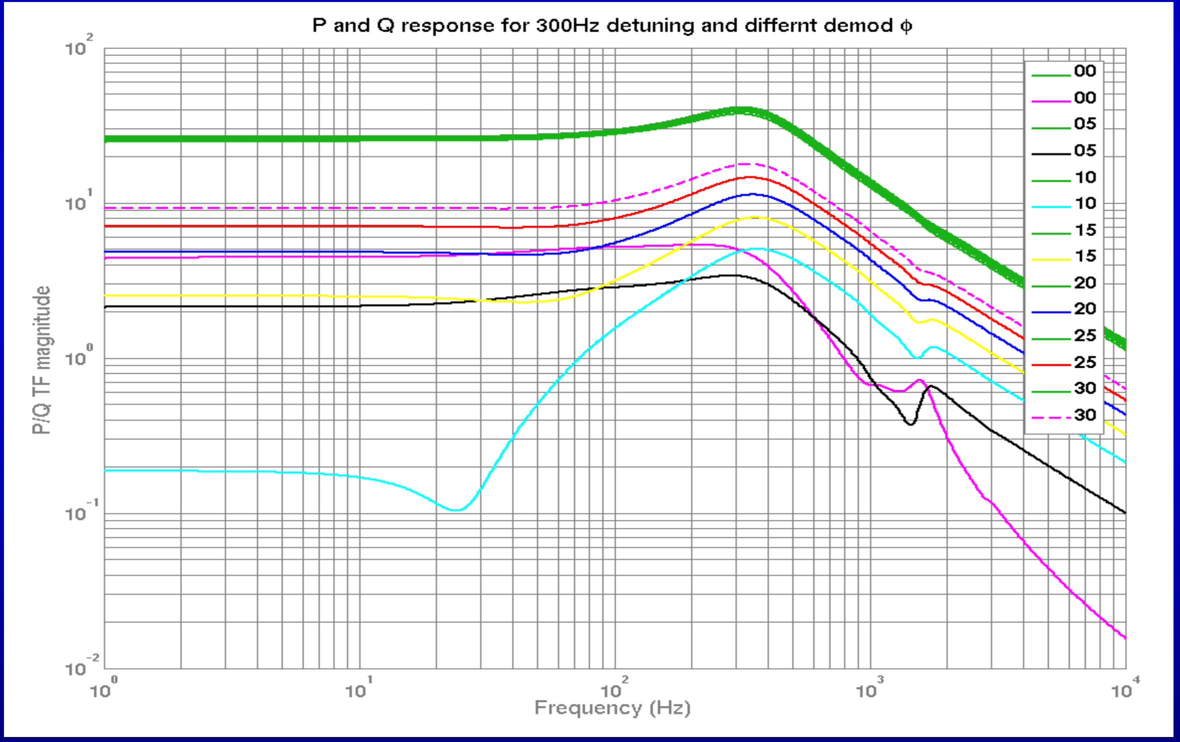
Using Signal recycling provides an increase of intracavity power of about 80%.

Future detectors will operate at much higher light levels.
Even with thermal compensation beam distortion might be a big problem.

<u>Two options:</u> **Mode healing** and/or **output mode cleaner**

Calibration of a GW detector with SR

When using Signal-Recycling (and RF readout) the GW-signal is spread over both quadratures. (The distribution is frequency dependent)

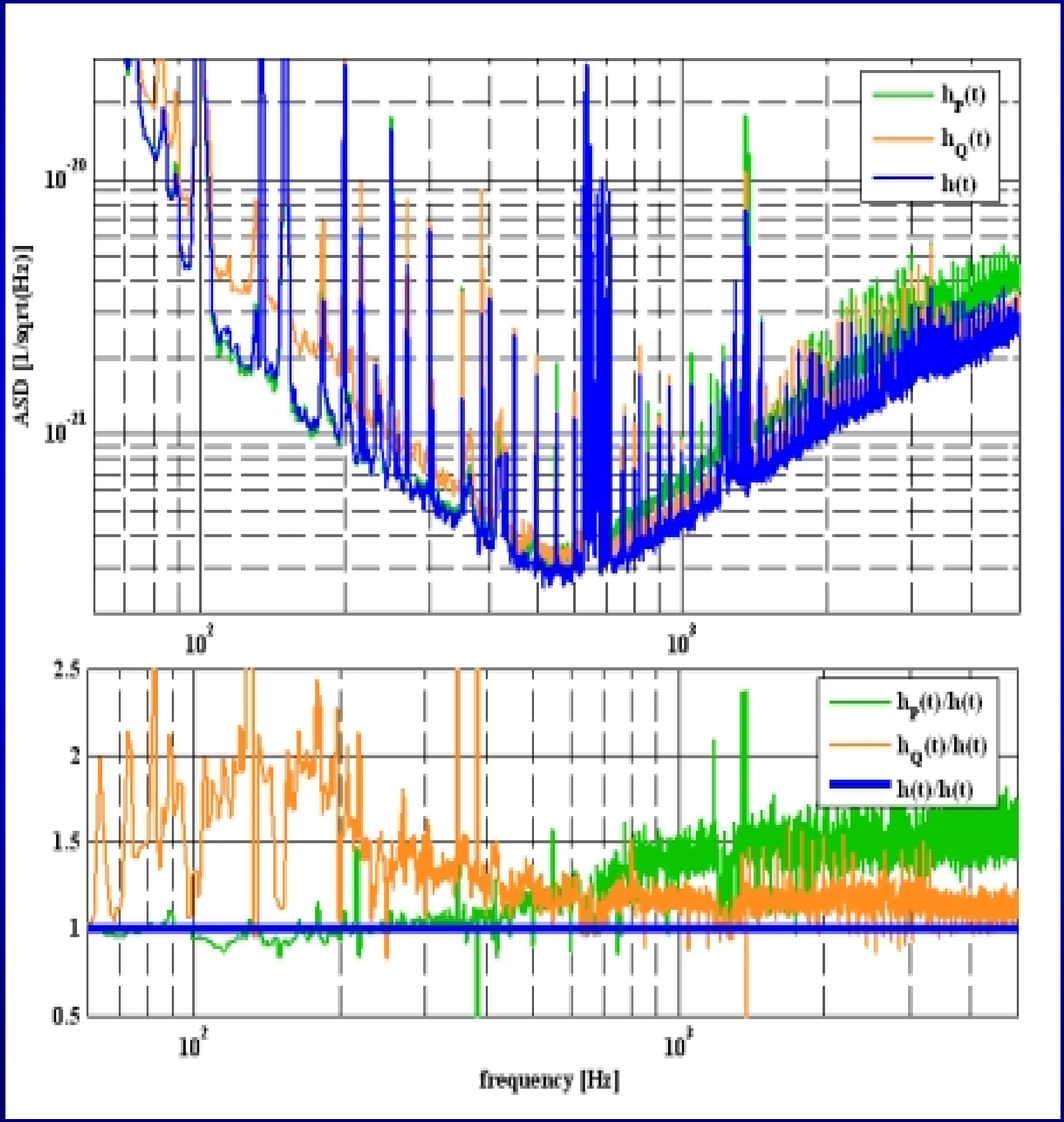


- You need to carefully choose the demodulation phase.
- You need to calibrate two signals.

Combining the two output quadratures

$$h_P(t) = h(t) + N_P(t)$$
$$h_Q(t) = h(t) + N_Q(t)$$

You can optimally combine the two calibrated signals to an h(t)-channel.

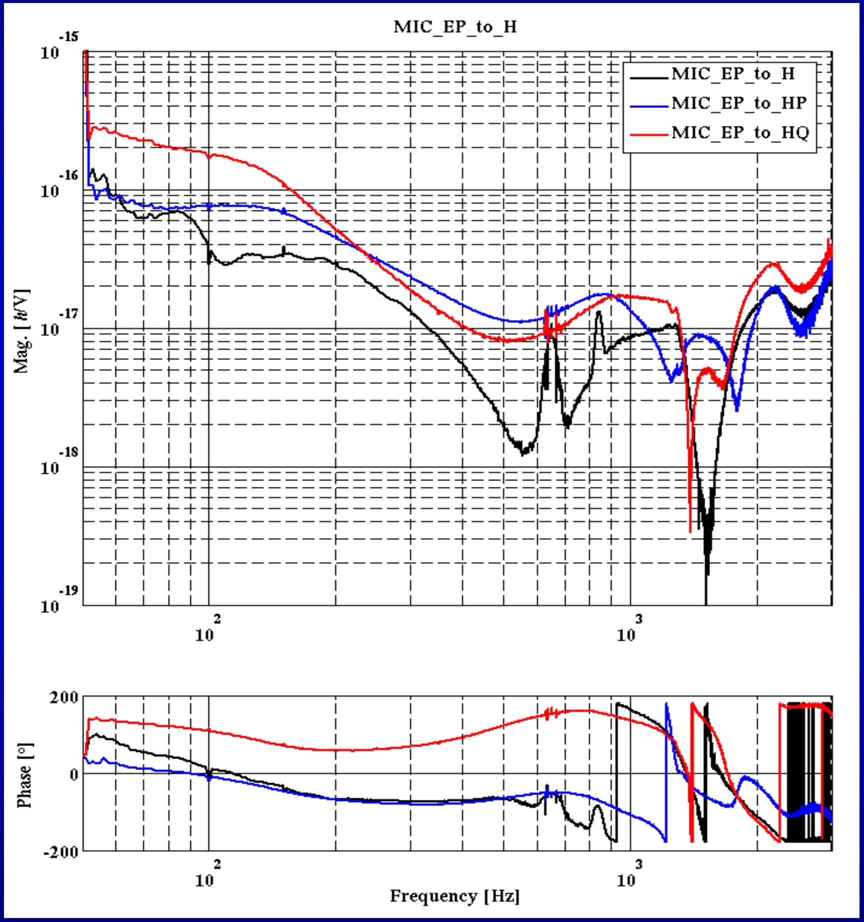


Advantages:

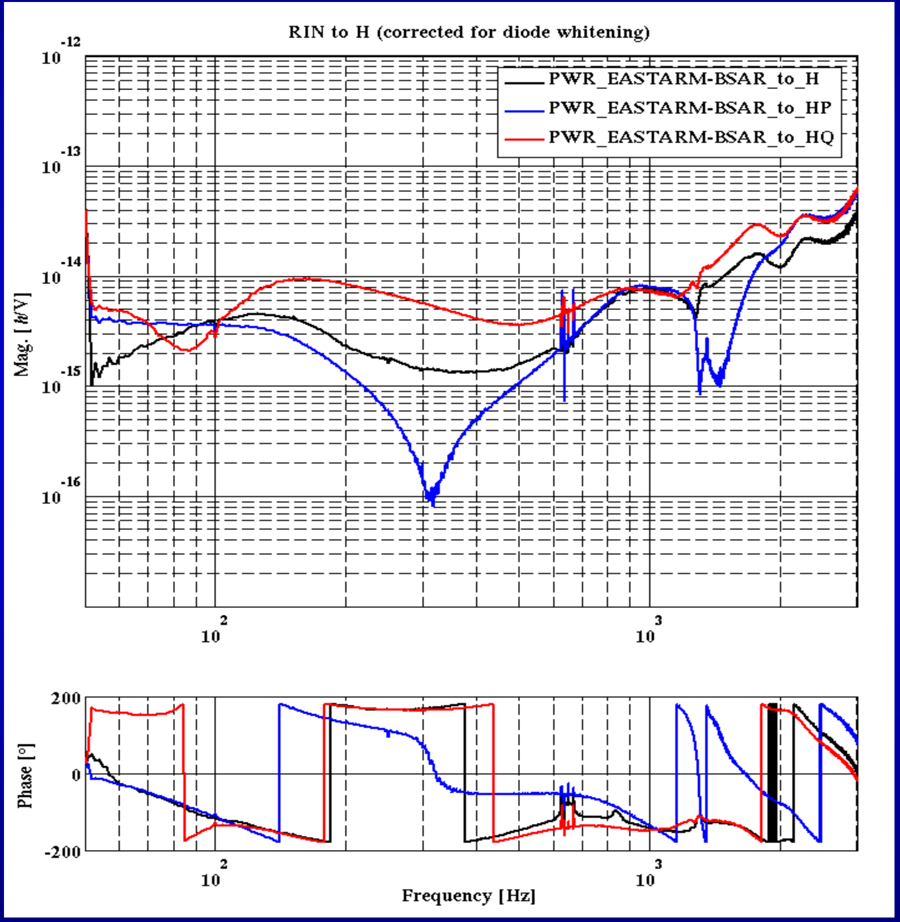
- h(t) has best GW content at all frequencies
- data analysists only need to handle a single signal

Detuned SR complicates various noise couplings and TFs

Frequency noise coupling to h(t)



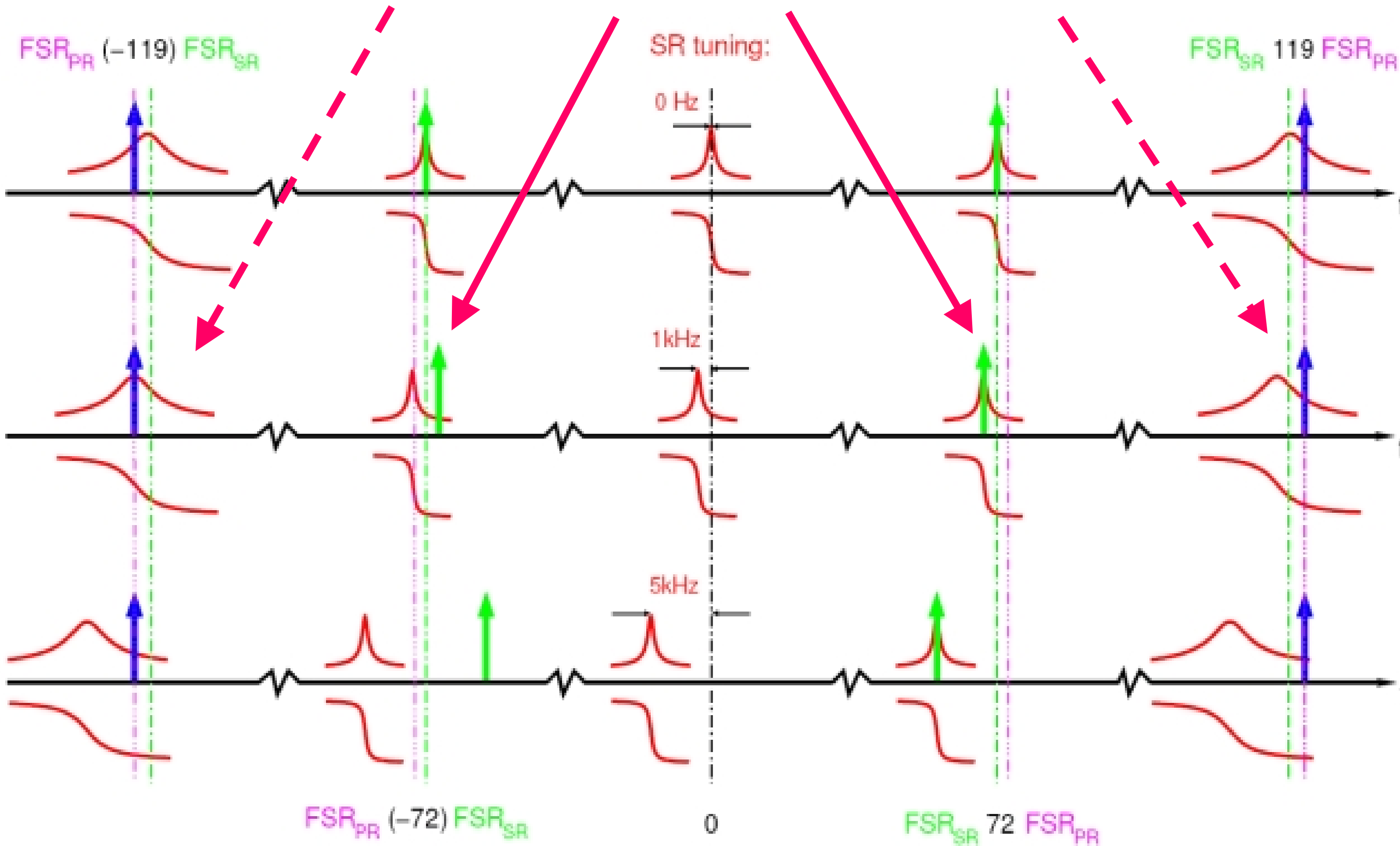
Laser amplitude noise coupling to h(t)



In a detuned detector TF may become complicated due to interaction and different resonance conditions of various sidebands.

Sideband picture for detuned SR

detuned SR = asymmetric sidebands



Summary

- Implementing SR is more than installing an additional mirror. (=> completely different detector)
- GEO demonstrated reliable operation of SR in a large scale GW detector
- Demonstration of detuned and tuned SR
- Advantages of SR
  - Shaping the detector response
  - Modehealing
- Problems connected to SR
  - More complex system (less intuitive understanding)
  - Complex noise couplings
  - GW signal in both output quadratures

End