# Coupling of the laser intensity noise in GEO600

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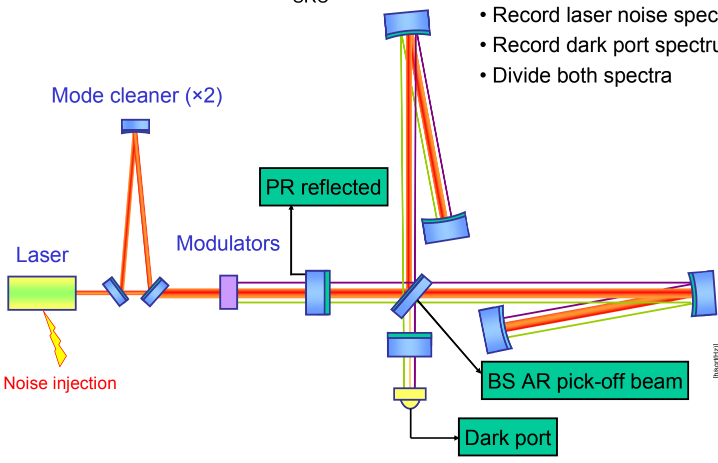
## Objectives

- Measure the transfer functions from the laser intensity noise to the detector outputs
- Understand the features seen in the measured transfer functions
- Demonstrate that the laser intensity noise does not limit the sensitivity in the heterodyne detection scheme
- Show how the laser intensity noise may limit the sensitivity of the homodyne detection

## Measuring optical transfer functions

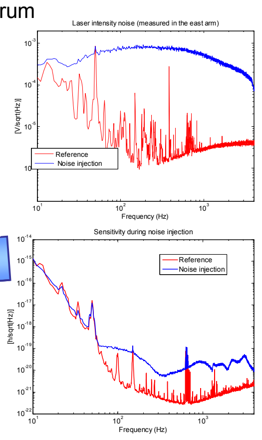
FSR = 125 kHz
$f_{MI}$ = 14.9 MHz
$f_{SR}$ = 9.01 MHz
} Sidebands frequencies are very close to be resonant in PRC and SRC




Optical layout of the dual recycling GEO600 gravitational wave detector with the main optical fields circulating inside the interferometer

How to measure the laser intensity noise TF to the dark port ?

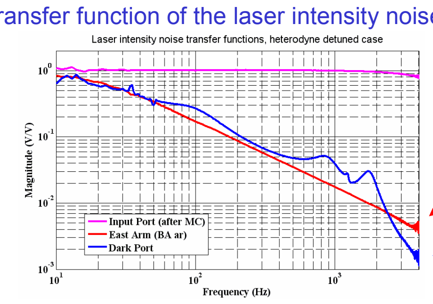
- Switch off laser power stabilisation loop
- Inject white noise into the laser intensity
- Record laser noise spectrum (PR ref or BS-AR)
- Record dark port spectrum
- Divide both spectra




*Examples of injected laser intensity noise measured in the east arm (top) and by h (bottom)*

## Laser intensity noise: tranfer function and projection

Transfer function of the laser intensity noise to various port:




Each mode cleaner act as a one pole low pass filter (cavity pole ~ 8kHz) for the laser intensity noise

The power recycling cavity is also a one pole low pass filter (PR cavity pole ~17Hz)

The transfer function to the dark port is more complex due to the presence of resonances (more in the second half of this poster)

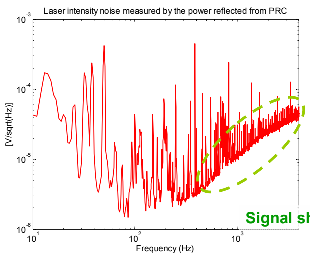
How to do noise projection...

In the frequency domain:

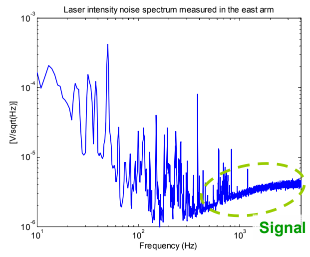
**Projected laser noise = measured laser noise × laser noise transfer function**

2 signals are usually used to measure the laser noise intensity:

- The beam reflected from the PRC
- The beam reflected from the BS AR coating

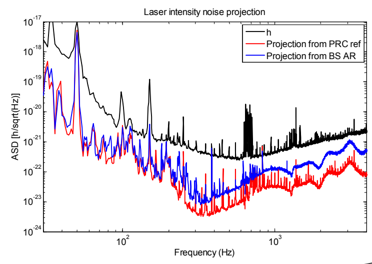



*(left) Typical spectrum of the laser power reflected from the power recycling cavity*




*(left) Typical spectrum of the laser intensity noise measured in the east arm by the llight reflected from the beamsplitter AR coating*

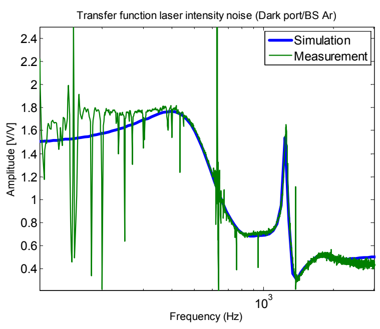
*(right) Example of laser intensity noise projection in the heterodyne detected detection case. At low frequency, the noise projection using the light reflected from the PRC and the light reflected by the beam splitter AR give similar results. However above 300 Hz, the results differ due to the shot noise limited signal used to measure the laser intensity noise. At these frequencies the curves represent an upper limit on the level of intensity noise in h.*




## Homodyne readout (detuned)

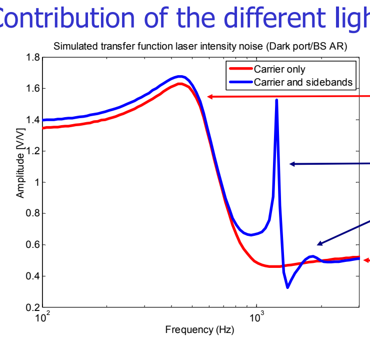
- Promising readout for advanced detectors
- Carrier light used as local oscillator to read GW signal
- Dark port light dominated by carrier light

### Laser intensity noise transfer function: East arm noise (BS AR) -> dark port



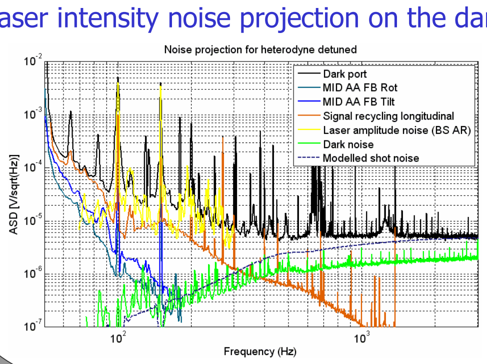

- Overall level of the transfer function depends on the dark port offset (i.e. the amount of carrier of light at the dark port) and the amplitude of higher order optical modes present at the dark port.
- The shape of laser noise intensity transfer function is highly sensitive to small variations of cavity lengths (order of mm).
- As everywhere else in this poster, the transfer functions simulations were done with the software finesse.

### Contribution of the different light field to the transfer function




- Transfer function dominated by carrier light
- Peak due to the signal recycling cavity (tuned at 550 Hz)
- Feature due to the Michelson sidebands being resonant in the power recycling cavity (1.3 kHz)
- Peak due to the resonance of the signal recycling sidebands in the signal recycling cavity (1.8 kHz)
- Flat response at high frequency due to the presence of higher order optical modes in the interferometer

### Laser intensity noise projection on the dark port: the noise budget

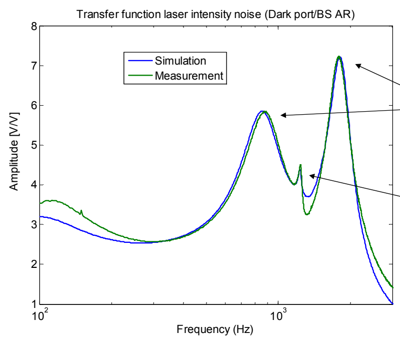



- The sensitvity is mainly limited by the signal recycling longitudinal control at low frequencies, laser intensity noise and unexplained noise from 200 Hz to 1 kHz, and then shot noise at high frequency
- The laser intensity noise only limit the sensitivity in a small frequency range (that is better than what was first expected when a dark fringe offset is introduced).

## Heterodyne readout (detuned)

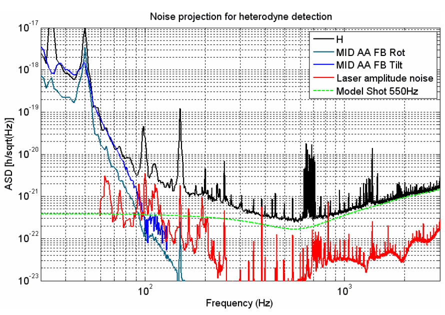
- Currently used by GEO for S5 (and by other detectors)
- Sidebands used as local oscillator to extract the GW signal
- Dark port light dominated by Michelson sidebands

### Laser intensity noise transfer function: East arm noise (BS AR) -> dark port




- Laser intensity noise is mainly carried to the dark port by the Michelson sidebands
- The 2 main peaks are due to the Michelson sidebands being resonant in the signal recycling cavity (only one central peak in case of tuned signal recycling).
- A little feature appears when the signal recycling sidebands are resonant in the power recycling cavity

### Laser intensity noise projection: the noise budget




- The sensitivity is mainly limited by auto alignement system in low frequency, unexplained noise from 100 Hz to 1 kHz and shot noise at high frequency
- The laser intensity noise is not a limiting noise (projection done using the light reflected from the PRC)

## Conclusion

- The laser intensity noise transfer functions were fully characterized and understood for both homodyne and heterodyne readout
- The transfer functions are largely different for both detection schemes
- In the current situation, the laser intensity noise will limit the sensitivity of GEO600 in low frequency if DC readout is implemented. This is already an encouraging result.