Signal-recycling cavity lock with a sub-carrier laser

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MOTIVATION

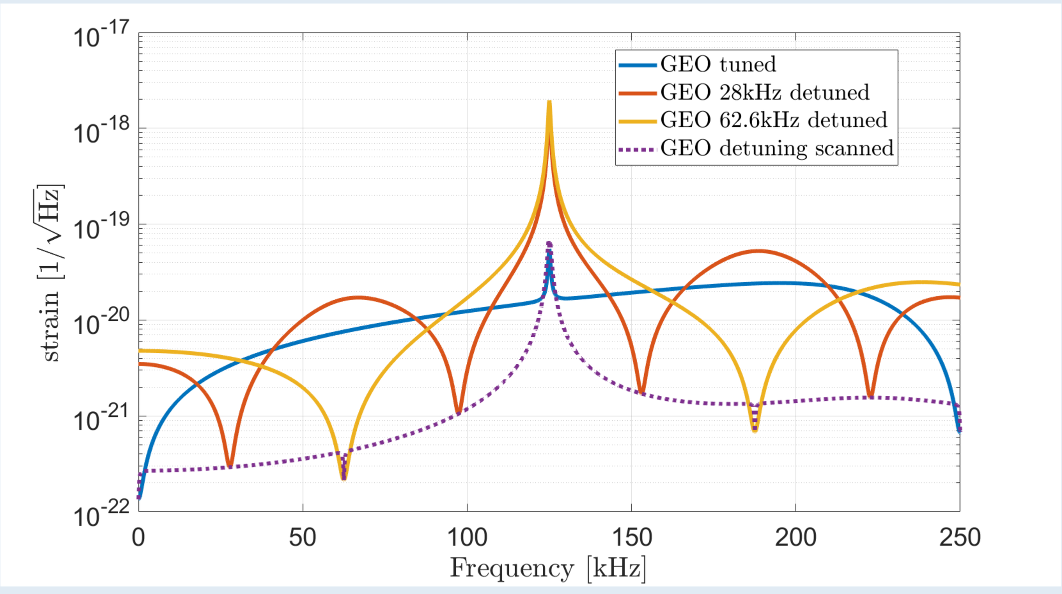


Fig.1: Sky-averaged shot-noise-limited sensitivity curves obtained for different tunings of the SRC. The purple trace is a collection of all the peak sensitivities.

The GEO VHF programme [1] aims to extend the calibrated frequency range of GEO600 to hundreds of kHz (Fig.1) in search of exotic signals at very high frequencies, such as the GWs produced by black hole superradiance [2] (Fig.2). This emission happens when a bosonic cloud, obtained from the scattering process between the BH potential and a massive scalar field , rotates around the BH.
The ability to detune the signal recycling cavity will play a crucial role in reshaping the response of the detector and making it more sensitive at the chosen frequency. The current control scheme, based on the Schnupp technique, is suboptimal for transitioning the detector from a tuned to a detuned configuration.

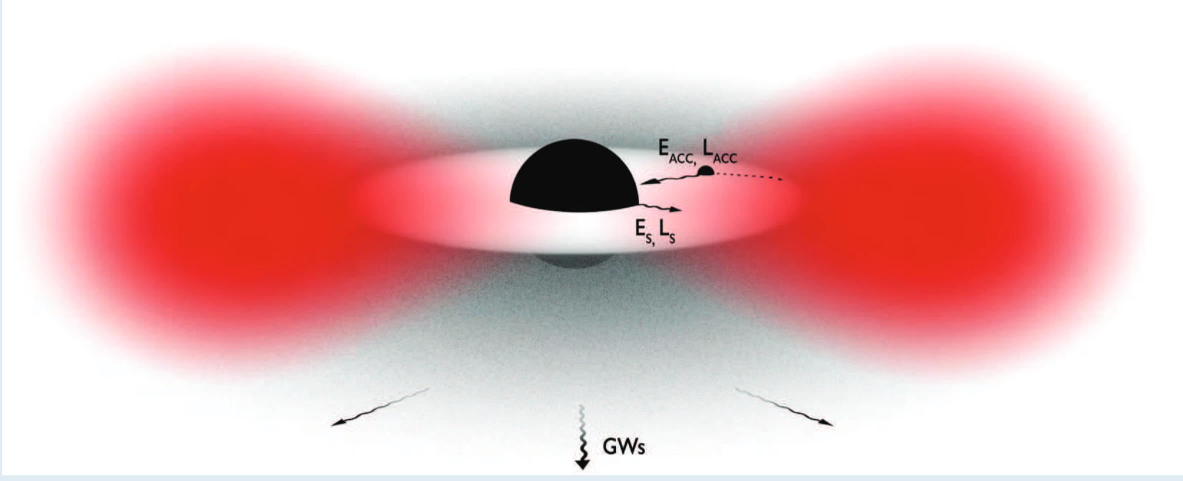
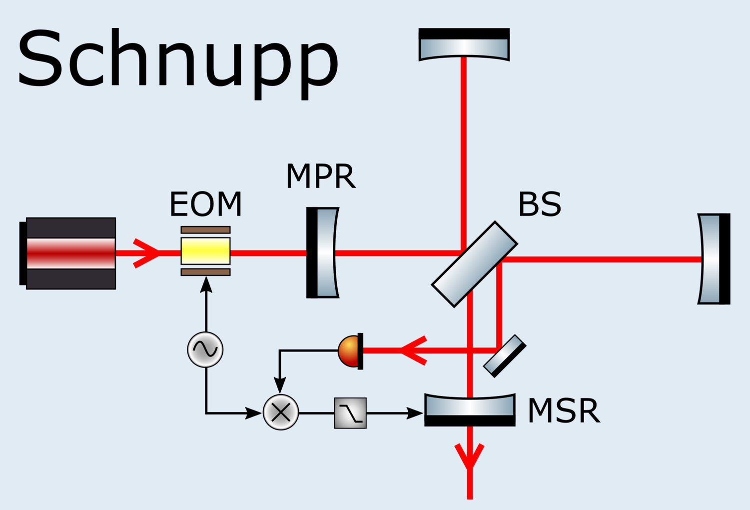


Fig.2: The expected frequency of the continuous GW emitted from a spinning BH of mass $1M_\odot$ and bosons of mass $\mu=10^{-11}$eV is ~10kHz.

METHODS



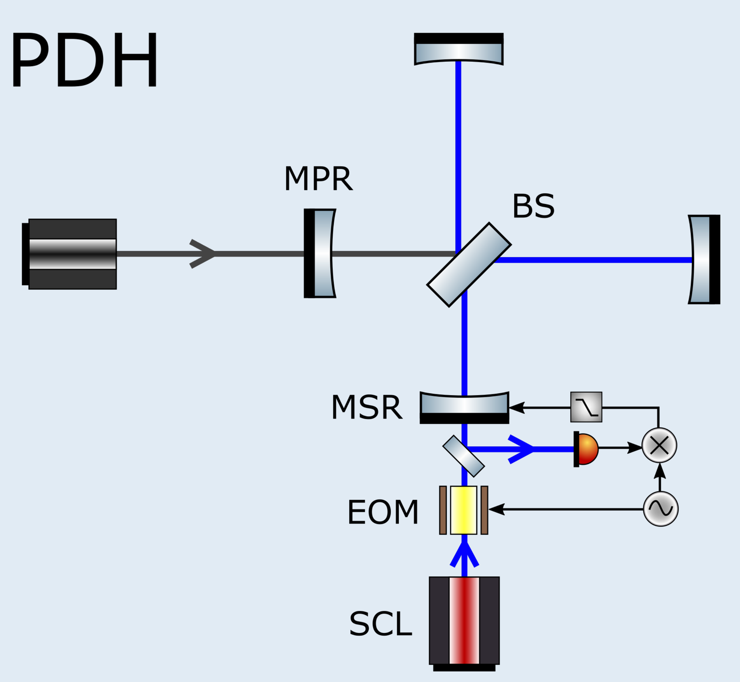


Fig.3: The Schnupp technique [3] is based on the phase modulation at the input of the interferometer. The error signal for the SRC longitudinal control is obtained after demodulation from the PD located in one of the AR ports of the BS.

Fig.4: With the new method, a frequency-shifted auxilliary laser, the sub-carrier laser (SCL), is injected through the dark port of the IFO. The error signal for the SRC locking is obtained using the PDH technique [4].

RESULTS

The SCL is locked to the main interferometer laser via PLL at ~2.8GHz. The frequency offset is chosen such as:

- the SCL is resonant w.r.t SRC
- the SCL is antiresonant w.r.t. OPO
- the SCL is antiresonant w.r.t. OMC

Because of the resonance condition with the SRC, the error signal obtained with the SCL is always symmetric, even with a detuned SRC.

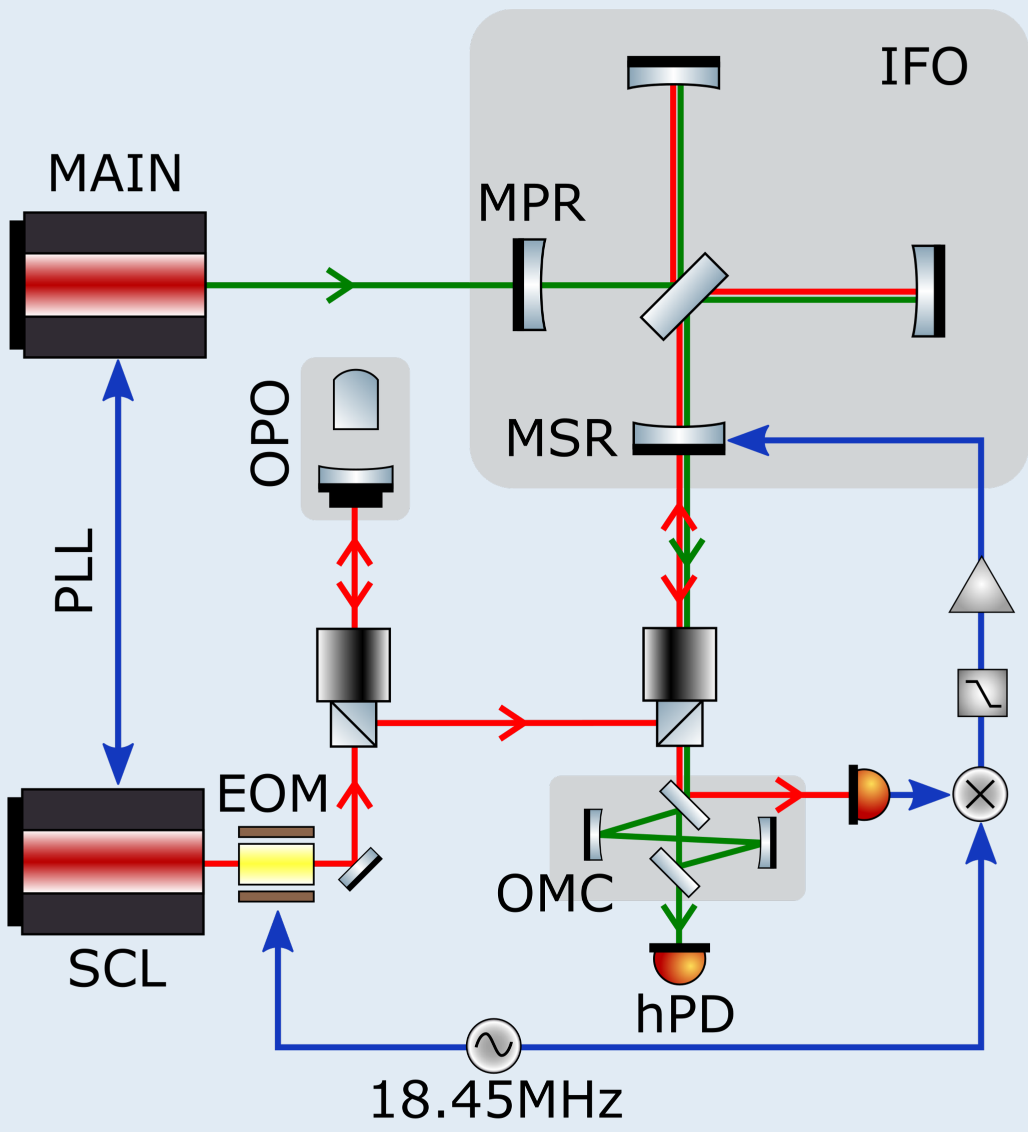


Fig.5: Complete scheme of the new technique. The green lines show the path of the main IFO laser, the red lines show the path of the SCL. The SCL is injected into the dark port of the IFO together with the squeezed light generated in the OPO. The two beams share the same path but do not interfere with each other due to the frequency shift of the SCL.
The phase modulation for the PDH error signal is obtained using an EOM. The error signal is obtained after demodulation of the PD signal in reflection of the OMC at the same frequency (18.45MHz).

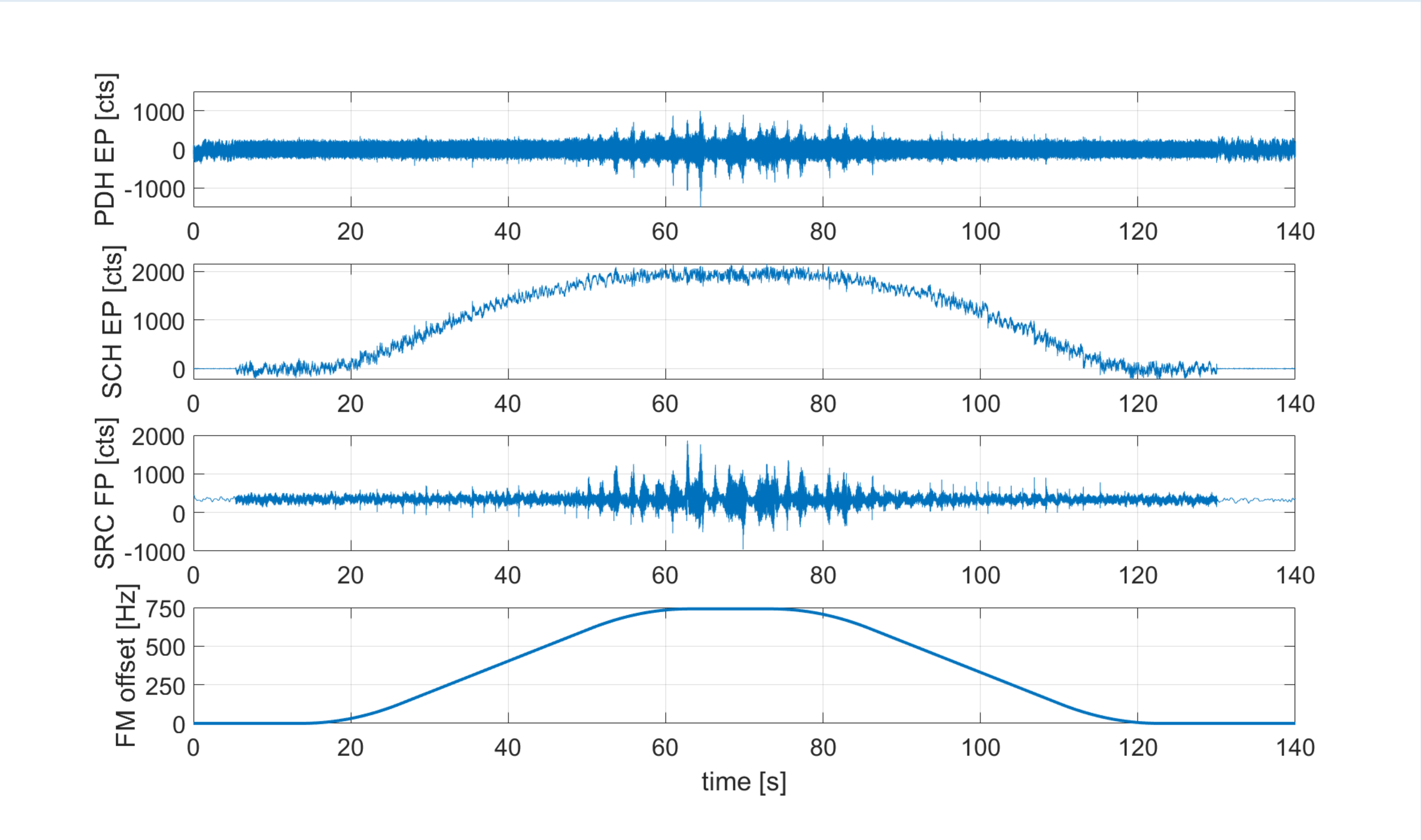


Fig.6: The plot shows the time series of different signals when the SRC was detuned from 0Hz to 750Hz and back using the new locking scheme.
At the time ~5.5s, the error signal employed to control the SRC was switched from the one obtained with the Schnupp technique to the new PDH error signal. The frequency of the SCL was then ramped by actuating on the FM input of the PLL's LO. The out-of-loop Schnupp EP shows that the SRC was actually detuned.

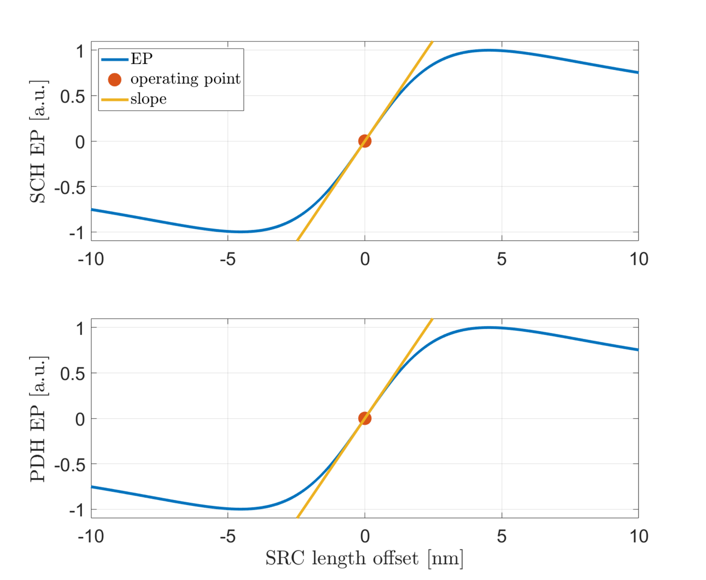


Fig.7: The two error signals look the same when the SRC is tuned...

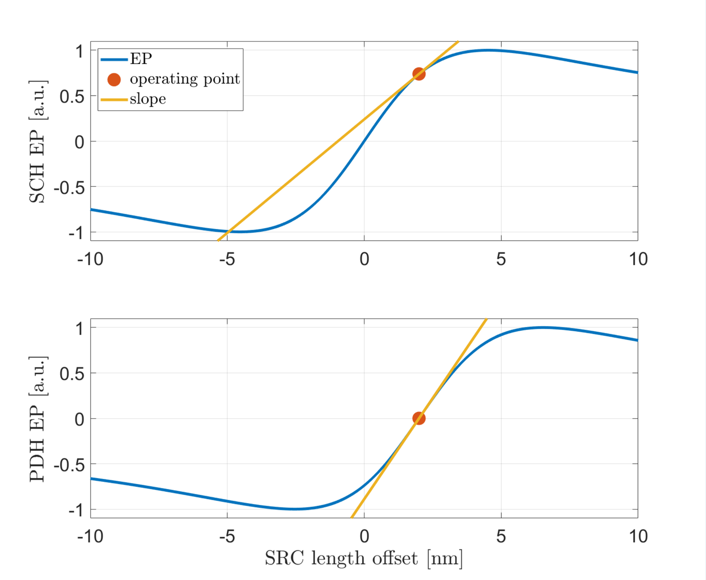


Fig.8: When the SRC is detuned, the operating point of the new error signal is kept at the zero-crossing value, and the slope is always the same. If the Schnupp error signal is used instead, one must add an offset to the EP and adjust the gain.

CONCLUSION

The new technique was successfully tested at GEO600 and a smooth detuning of the SRC was possible.
The new error signal is inherently decoupled from other degrees of freedom of the IFO [5] .
Testing this new technique for the SRC length control at GEO600 was a first step towards its possible implementation in future detectors, such as ET-LF. This detector is expected to operate in a detuned configuration and the need to decouple the sensing of the MSR from other degrees of freedom will be even more stringent, since the observation band will overlap with the control band of the SRC.

ABBREVIATIONS

BS: Beam Splitter
EOM: Electro-Optic Modulator
EP: Error Point
FM: Frequency Modulation
FP: Feedback Point
hPD: 'h' PhotoDiode
IFO: InterFerOmeter
MPR: Power Recycling Mirror
MSR: Signal Recycling Mirror
OMC: Output Mode Cleaner
OPO: Optical Parametric Oscillator
PDH: Pound-Drever-Hall
PLL: Phase Locked Loop
SCH: SCHnupp
SCL: Sub-Carrier Laser
SRC: Signal Recycling Cavity

REFERENCES

[1] LIGO document G2302390
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[3] Lise Schnupp. "Presentation at european collaboration meeting on interferometric detection of gravitational waves". Sorrento, Italy (1988).
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[5] Adya, V. "Ways to stop mirrors from moving unnecessarily: design of advanced gravitational wave detectors". PhD thesis. Leibniz Universität Hannover (2018).