STRAY LIGHT PROBLEMS IN INTERFERO-METRIC GRAVITATIONAL WAVE DETECTORS

S. Hild, H. Grote, M. Hewitson, H. Lück, K.A. Strain, J.R. Smith and B. Willke

Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut)

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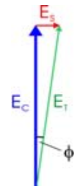
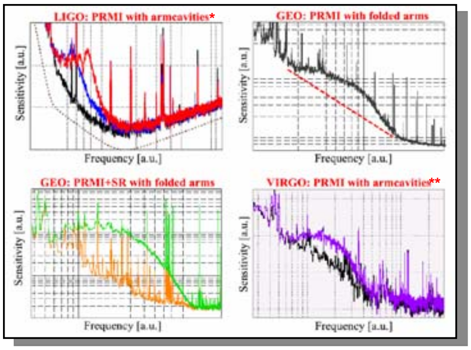
Introduction

- Stray light problems have been encountered during the commissioning of **all** currently operating large scale gravitational wave detectors.
- The underlying principle of all these interferometers is to make an **extremely sensitive phase measurement**. Therefore even tiny stray light contributions with a **varying phase** will harm the measurement.
- The currently achieved sensitivity of GEO600 can already be spoiled by stray light of the order **10^{-20} W** !





* LLO electronic log 2005-08-19 (B O Reilly, personal communication).

** "2nd Report on WG1: Antennas commissioning and characterization", MBarsuglia, A Freise, I Fiori, H Grote, H Heitmann, S Hild, P LaPenna, G Losurdo, H Lück, J Smith, L Taffarello, G Vajente, M Visco, B Willke, 2006.

- **Since 2nd generation GW detectors will aim for significantly increased sensitivities at low frequencies, stray light will be even more problematic.**

Cat's eye effect

- **Any scattering source close to a beam waist is extremely harmful !**
- Example: An ideal cosine scattering source of 5x5μm.

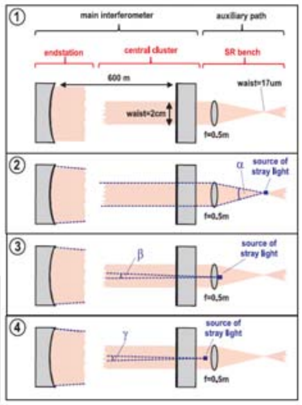
$$A_{4\mathrm{back}} \propto A_4 \int_0^{\gamma/2} \cos(\varphi)\, d\varphi.$$

- The backscattering efficiency of scenario 2 is **1.6 billion times larger** than of the scenarios 3 and 4.

When the scattering source sits at the beam waist:

1. A larger fraction of the light is scattered.

2. The acceptance angle for reentering the interferometer mode is much larger.



The filter experiment

An easy way **to identify limiting scattering sources** in an auxiliary optical path **by attenuating** the lightlevel in this path.

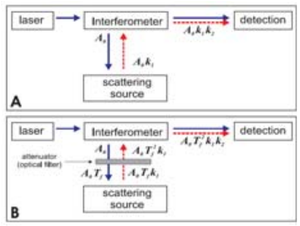
A_0: Light amplitude entering the auxiliary beam path of interest.

k_1: Scattering coefficient

k_2: Coefficient for reentering the main interferometer

T_f: Amplitude transmission of optical attenuator

Overall the light amplitude re-entering the detection path is reduced from $A_0 \cdot k_1 \cdot k_2$ **to** $A_0 \cdot T_f^2 \cdot k_1 \cdot k_2$ by inserting the optical attenuator.



Controlled stray light injection

A device for controlled stray light generation:

Need a scattering surface that can be controlled in frequency and amplitude.

Realization:
Using an commercial low-cost loudspeaker with a rough and silvery metal diaphragm (anodised aluminium).

A: Low frequency large amplitude scenario:

Scattering source moves with very low frequency (outside the detection band) but with an amplitude of many wavelengths. A scattering shoulder is produced with a cutoff frequency:

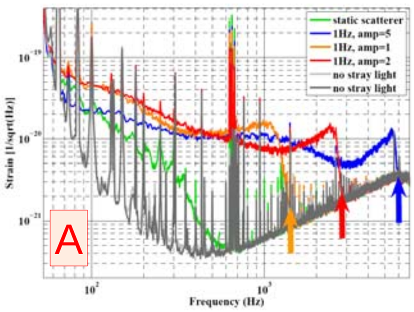
$$f_{\mathrm{cutoff}} \approx 4 \cdot f_{\mathrm{sp}} \cdot \frac{A_{\mathrm{sp}}}{\lambda_{\mathrm{laser}}}$$

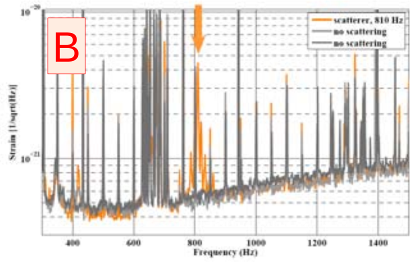
B: High frequency low amplitude scenario:

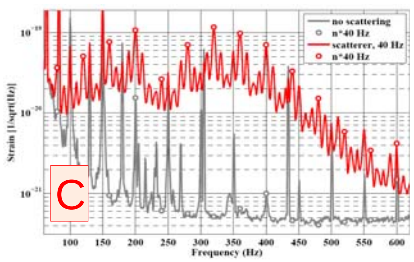
Scattering soure moves with frequency in detection band. Only a small amplitude is necessary to produce a stray light peak at corresponding frequency

C: Combination of scenario A and B:

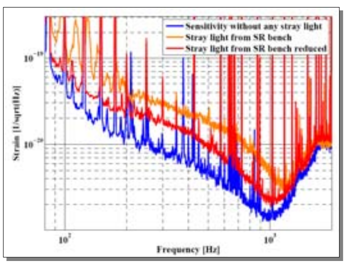
Produces a scattering shoulder with a comb of harmonics of the excitation frequency.

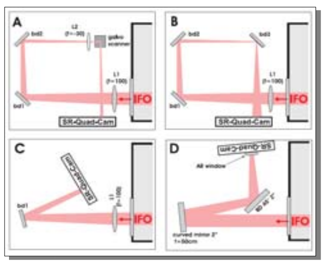






Illustrative example: GEO's SR-bench



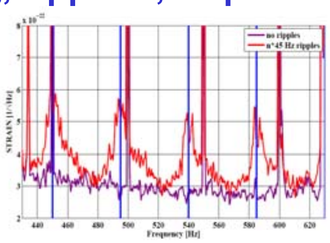


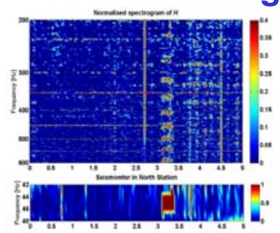
Sensitivity progress of GEO600 from autumn 2004:
By eliminating stray light from the signal recycling bench the sensitivity of the GEO600 detector was improved by a factor of about 3 for frequencies between 100Hz and 1000Hz.

Rules to avoid scattered light problems:

1. *If possible, avoid the presence of any beam waist.*
2. *Avoid placing components close to a waist.*
3. *Only use high quality optics (superpolished, low scatter, etc).*
4. *Only use large optics (avoid clipping)*
5. *Properly dump all secondary beams.*
6. *Avoid the use of lenses (to avoid reflection at normal incidence).*

„Ripples", a special form of scattering





„Ripples" are a series of equidistant peaks of scattered light noise originating from a vibrating scattering source (in this case a viewport).