Summary of Stray Light Mitigation Strategies at 2G interferometers

Mario Martínez

ICREA IFAE
Outline

• IFT layout and stray light
• Baffles/baffles
• Long arms baffling
• Suspended vs non-suspended
• Baffles in Core Optics
• CryoBaffles
• R&D on materials
• Large angle stray Light in benches*
• Towards acting monitoring

• Final notes on future

See talk by Beatrice D'Angelo on Dust in Optics
See talk by Michal Was on Bench Optics

Collecting highlights from more than a decade of SLC work at Virgo.

See talk by Alena Ananyeva @ LIGO

* Not including work on suspended benches
About 100 W would be diffused light in the interferometer (80% for 125 W input)

Most of the light at small angles close to the mirrors → Dictated by the mirror maps/defects
Larger angles going to core-optics/cryo stations
Scattered light in long tube much smaller but can kill the GW signal if not mitigated.

A re-coupling of $10^{24}$ W/W enough to destroy the expected GW signal
Need to put baffles almost everywhere

→ Important to understand the intensity of the light to determine potential damage
Different materials in different places

→ Important to understand baffle vibrations

\[ \Delta \phi = \frac{4\pi}{\lambda} \times (f) \text{ Power}^{1/2} \]

Re-coupled photons propagates vibrations
Inducing a phase fluctuation faking GWs
Computing SLC noise

1. Use FFT simulation to understand light illuminating baffle
   • Needs mirror maps
2. Use FFT to understand how much couples back to ITF
   • Baffle as intra cavity source with effective map
3. Using Optickle to compute the Transfer function from baffle displacement to dark Fringe → tricks on how to model ITF

→ Given a baffle displacement translate into \( h(f) \) sensitivity
→ Validate with data (injection tests)

\[
\tilde{x}_{baf}(\omega) = \frac{\lambda}{4\pi} \sqrt{\text{PSD} \left[ \sin \left( \frac{4\pi}{\lambda} \tilde{x}_{baf}(t) \right) \right]}
\]

\[
h_{\text{noise}}(\omega) = \frac{TF_{B1/baf}}{TF_{B1/DARM}} \frac{1}{L_{arm}} c_{xx} \tilde{x}_{baf}(\omega)
\]
Scattered light noise in gravitational wave interferometric detectors: A statistical approach

Jean-Yves Vinet
Laboratoire d’Optique Appliquée, Ecole Polytechnique, 91120 Palaiseau, France

Violette Brisson
Laboratoire de l’Accélérateur Linéaire, Bat. 208, Université Paris-Sud, 91405 Orsay, France

Scattered light noise in gravitational wave interferometric detectors: Coherent effects

Jean-Yves Vinet
Laboratoire d’Optique Appliquée, Ecole Polytechnique, 91120 Palaiseau, France

Violette Brisson
Groupe Virgo, Laboratoire de l’Accélérateur Linéaire, Bat. 208, Université Paris-Sud, 91405 Orsay, France

II. BASIC THEORY OF COHERENT SCATTERED LIGHT NOISE

A. Emission of scattered light

... (See references to Vinet, Brisson, Braccini, Ferrante, Pinard, Bondu, Tournie, and Thorne)


→ Demonstrate the need for chain of baffles in main arms
→ Following work by K.S. Thorne in 1989
→ As a result 160 baffles in each main arm
→ R&D on edge shape led to the serrate solution
Baffles in long arms

Calculations indicate that serrate shapes reduce drastically the reflectivity and diffraction effects.

Early on injection studies indicated the noise is below the required sensitivity.
Given all the approximations one needs to be 1/10 of designed sensitivity (at least)

→ Here it is clear you need to suspend the baffles in the core optics
Notes on Materials

Intense R&D on materials for the baffles by the time of the preparation for Virgo

<table>
<thead>
<tr>
<th>Material</th>
<th>LIDT</th>
<th>TIS</th>
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<tbody>
<tr>
<td>SiC + AR</td>
<td>30kW/cm²</td>
<td>~20-50ppm</td>
</tr>
<tr>
<td>DLC + AR</td>
<td>500W/cm²</td>
<td>~500-1000ppm</td>
</tr>
<tr>
<td>AR-on-steel</td>
<td>&gt;50W/cm²</td>
<td>~300-500ppm</td>
</tr>
<tr>
<td>Abs. Glass + AR</td>
<td>~1W/cm²</td>
<td>~100ppm</td>
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</tbody>
</table>

Other important considerations:
- Temperature dependence
- Scalability with surface dimension
- Reproducibility
- Cost (no much SiC+AR used)
Intensive R&D on Diamond-like Carbon (DLC) indicated. It can be used in places with large exposure. 
→ INJ baffle and part of the baffles in the cryotrap.

DLC showed large TIS largely dependent on thickness. Some issues with DLC+AR coating reproducibility.

→ Massive presence of Stainless-Steel (SS) + AR coating.
IMC

INJ Baffle made out of DLC + AR-coating given the intensity of the light (up to 1kW/cm²)

IMC end mirror baffle made out of SS
Cryotraps

Requires slightly different treatment since this refers to wide angles (FFT is not so valid)

Aperture dictated by the coupling $< 10^{-24}$ W/W
→ Being reviewed now for AdV+ phase II (end mirrors)

Special campaign to understand the vibration modes of the baffle and how this would affect the ITF
Cryo Baffle Vibrations

Using shakers and accelerometers to understand the eigenmodes
Central Optics Baffles

Combination of SS+AR, DCL+AR
Full study of vibrations to facilitate Noise hunting (VIR-0147A-16)
The intensity in the baffles in the arms is very small $\rightarrow$ SS + AR massively used.

The towers walls needed to be blacked to suppress scattering from the mirrors at large angles $\rightarrow$ original (fragile) glass-AR Replaced gradually by SS-AR
New installed FDS system required (2021) additional doubly coated baffles 532/1064 nm to reduce the SL contamination.

See talk by Eleonora Polini.
SL in benches (DET tower)

\[ h(t) = G \cdot \sin\left(2 \cdot \frac{2\pi}{\lambda} \cdot x(t)\right) \]

Studies to place baffles at the tower walls instead of suspending them.

→ The solution must be at the bench to suppress SL and ghost beams with baffles/diaphragms.

To the wall
Towards active SLC monitoring

- AdV+ is bringing a new concept for active monitoring of the stray light in the main cavities
  - Evolution of mirror maps
  - Alignment and HOMs detection
  - Correlation with glitches
  - Validation of SLC simulations

- A demonstrator of the technology in the form of an instrumented baffle in the Input Mode Cleaner is now in place in AdV+
  - In commissioning @ EGO
  - To be integral part of O4 operations
  - A step towards instrumenting main mirrors in long arms in O5

See Ll. Mir talk on the subject
Notes for the future

• In preparation for 3G projects

• R&D on new materials with larger absorption and higher damage thresholds \(\rightarrow\) we wavelengths for ET-LH will require a new R&D campaign and certification

• Better simulation tools to propagate the SL effects into GW sensitivity (including also benches)

• A richer network of displacement monitors embedded in the baffle systems (in the original Virgo plan and excluded due to funding/timing) should be a reality for ET

• An active monitoring approach to control SL inside cavities using instrumented baffles in strategic locations (suspended mirrors, cryotrap, etc....)