SCATTERED LIGHT

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On behalf of the Virgo and LISA people involved in the straylight studies

GDR – Observatoire de Paris - June 20, 2012

Straylight may affect the performances of many optical systems

• Straylight: light from the source itself that is following a different path from the intended one

Due to
- ✓ Reflection from AR
- ✓ Imperfect mirror surfaces
- ✓ Surface defects (dust, scratches, digs)
- ✓ Enclosure of the system
- ✓ Diffraction from the aperture of the optics

• Straylight in GW detectors identified as a serious issue: *R. Schilling, et al., "A method to blot out scattered light effects and its application to a gravitational wave detector," J. Phys. E: Sci. Instrum.14(65),(1981)*

➢ Taking into account for the design of the first generation GW interferometers

- E. Flanagan, et al. "Noise due to backscatter off baffles, the nearby wall and objects at the far end of the beam tube; and recommended actions," LIGO Technical Report, LIGO-T940063-00 (1994).
- J-Y. Vinet, et al., "Scattered light noise in gravitational wave interferometric detectors: coherent effects," Phys. Rev. D54, 1276 (1996).
- J-Y. Vinet, et al., "Scattered light noise in gravitational wave interferometric detectors: a statistical approach," Phys. Rev. D 56, 6085 (1997).
- B. Canuel et al., "Determination of back scattering and direct reflection recoupling from single optics - application to the end benches," Virgo internal document VIR-0375A-10 (2010),

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➢ Major concern for LISA and second generation of ground based ITF

- Spector, et al., "Back-reflection from a Cassegrain telescope for space-based interferometric gravitational-wave detectors," Class. Quantum Grav.29, 205005 (2012)
- D. J. Ottaway, et al., "Impact of upconverted scattered light on advanced interferometric gravitational wave detectors," Opt. Express 20, 8329-8336 (2012)

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Straylight may affect the performances of many optical systems

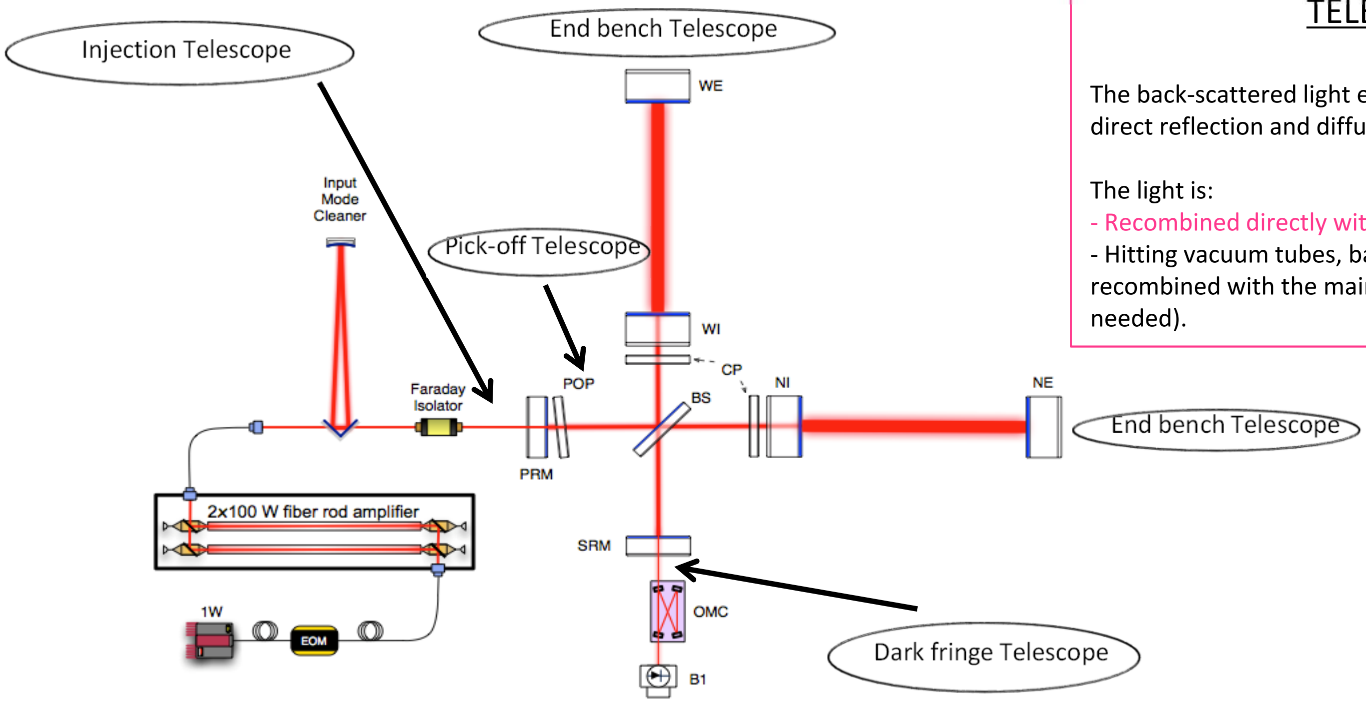
• For the first generation of GW interferometers, many issues have been identified as originating from the scattered light of some optics

- The Virgo Collaboration, “Noise studies during the first Virgo science run and after,” Class. Quantum Grav. 25, 184003 (2008).
- The Virgo Collaboration, “Noise from scattered light in the Virgos second science run data,” Class. Quantum Grav. 27, 194011 (2010).

➡ It is crucial to calculate accurately the light which is re-couples to the ITF for every critical optical element in order to:

- set its optical requirements
- make important optical setup design choices

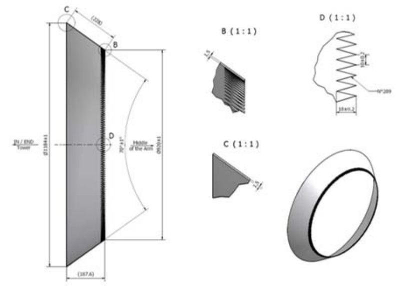
GROUND BASED DETECTOR: VIRGO



TELESCOPE STUDIES

The back-scattered light emitted by optics can be separated in direct reflection and diffusion.

The light is:
- Recombined directly with the main beam (a small fraction)
- Hitting vacuum tubes, baffles (most of the light), and is recombined with the main beam (proper dumping of this light needed).



SLC: Stray Light Control SUBSYSTEM

The subsystem is meant to deal with all the light which goes out of the clear aperture of the core optics
It has to define the baffles into the vacuum chambers of the ITF required to absorb, as much as it is necessary, the straylight.

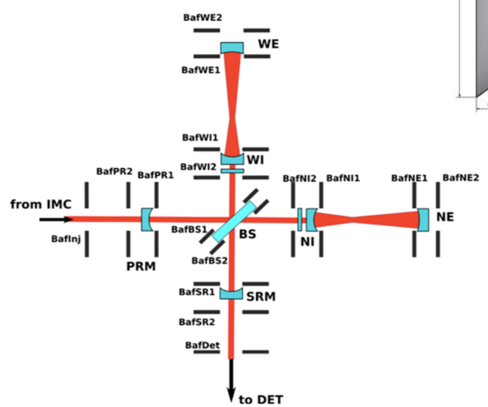
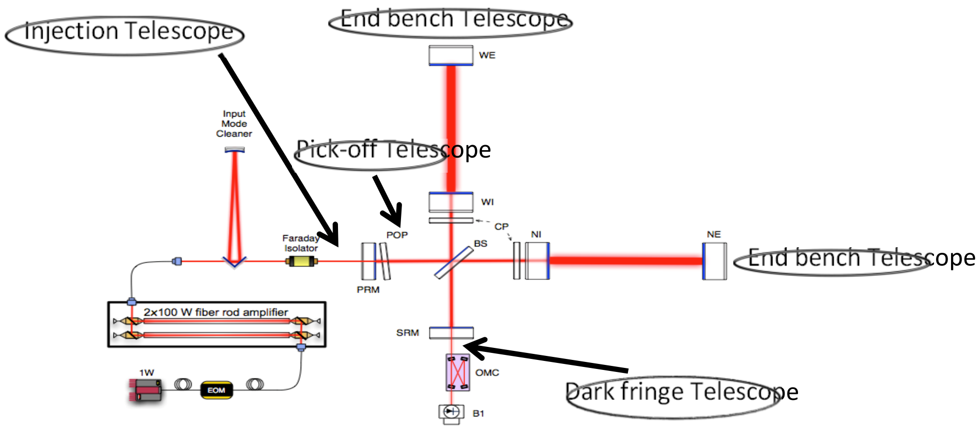


Figure 9.12: Layout of the baffles suspended to the Super Attenuators.

COUPLING MECHANISMS

The field back-scattered by an optic carries a phase noise given by: $\phi_{sc} = \frac{4\pi}{\lambda}(x_0 + \delta x)$



End benches example: diffused light produces a change in the phase inside the FP cavities which mimic a GW

$$h = \sqrt{f_{sc}}T\frac{\lambda}{4\pi}\frac{1}{L}\sin(\phi) = \sqrt{f_{sc}}K_{end}\sin(\phi)$$

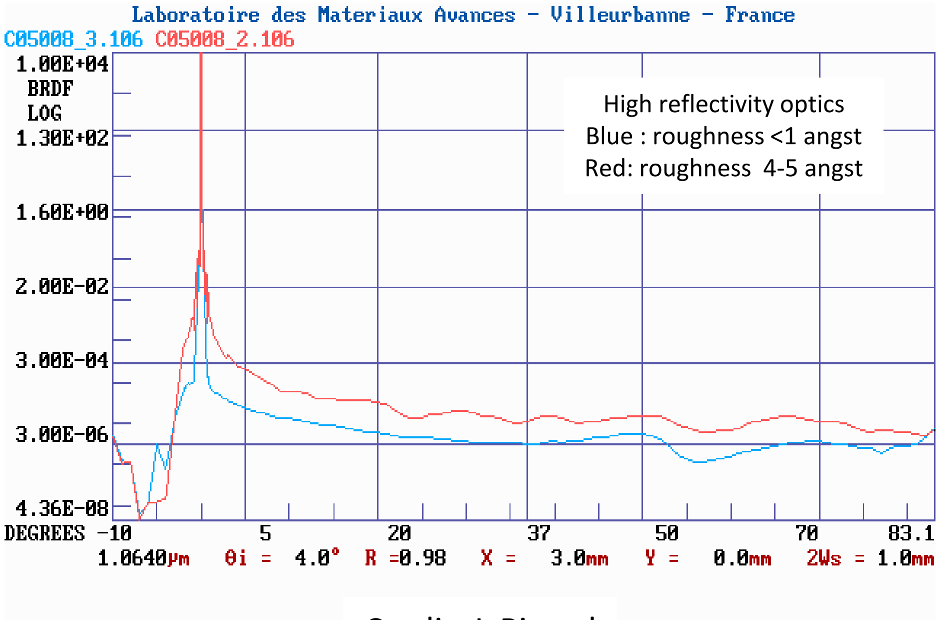
$$K_{end} = T\frac{\lambda}{4\pi}\frac{1}{L}$$

f_{sc} is the fraction of the back-scattered light recombined with the main beam, T is the transmission of the cavity mirror, L the length of the arm

The coupling mechanism has to be computed for each optics position (VIR-0211A-12)

AMOUNT OF BACK-SCATTERED LIGHT(1)

Non normal incidence optics



Credit: L.Pinard

Superpolished optics (~ 3 angst)

- TIS=10 ppm, BRDF=$3x10^{-6}$ $strd^{-1}$

Parabolic mirrors (roughness ~ 1 nm)

- TIS=150 ppm, BRDF= $50x50^{-6}$ $strd^{-1}$

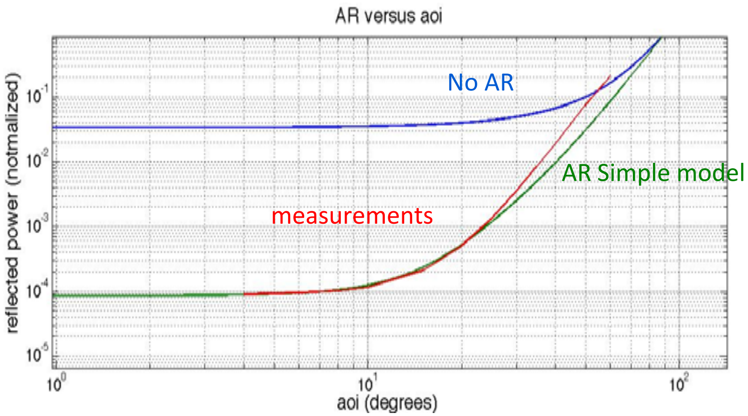
f_{sc}=BRDF x Ω

Computation of the solid angle of the recombined light (Ω) with an analytical code at EGO and a matlab code (ADOC-APC Diffusion of Optics Code) using geometrical optics.

ADOC propagates optical rays over the optical system taking into account the apertures

AMOUNT OF BACK-SCATTERED LIGHT(2)

Lenses at normal incidence



- AR coating constant within ~10° AOI (LMA).
- Hypothesis: diffracted waves see same (constant) reflectivity of the AR coating for angles <few degrees.
- Measurements needed to confirm it

$$f_{sc} = \left|\langle \Psi(x,y) | \phi_0(x,y) \rangle\right|^2 = \left|\langle e^{2ikf(x,y)} \phi(x,y) | \phi_0(x,y) \rangle\right|^2 \cong \left|\langle \phi(x,y) | \phi_0(x,y) \rangle\right|^2$$

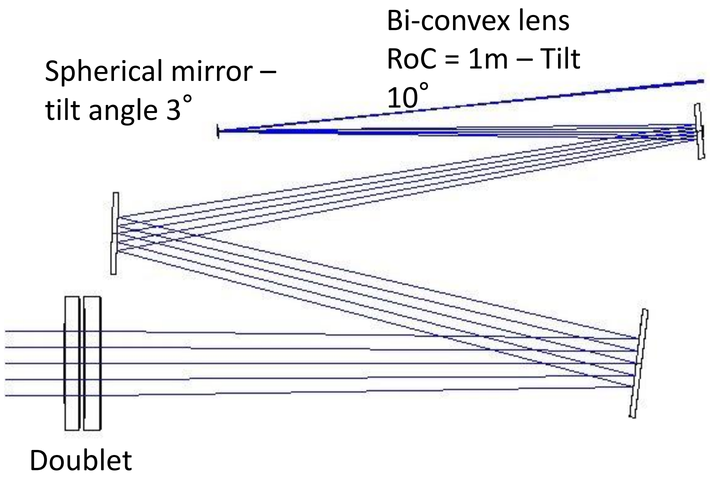
fsc=R_{AR} x overlap integral

AMOUNT OF BACK-SCATTERED LIGHT(3)

End bench Telescope (ADOC)

Optics	fsc
Doublet (4 sides)	$5 \cdot 10^{-10}$ (RAR 0.5%)
L2	$5 \cdot 10^{-8}$ (RAR 100ppm)
Steering mirrors (for 3)	10^{-14} (TIS 10ppm)

Small lens (fsc ~ 10^{-8}) can't be tilted, but a back-up solution with a configuration using a spherical mirror and a tilted lens.

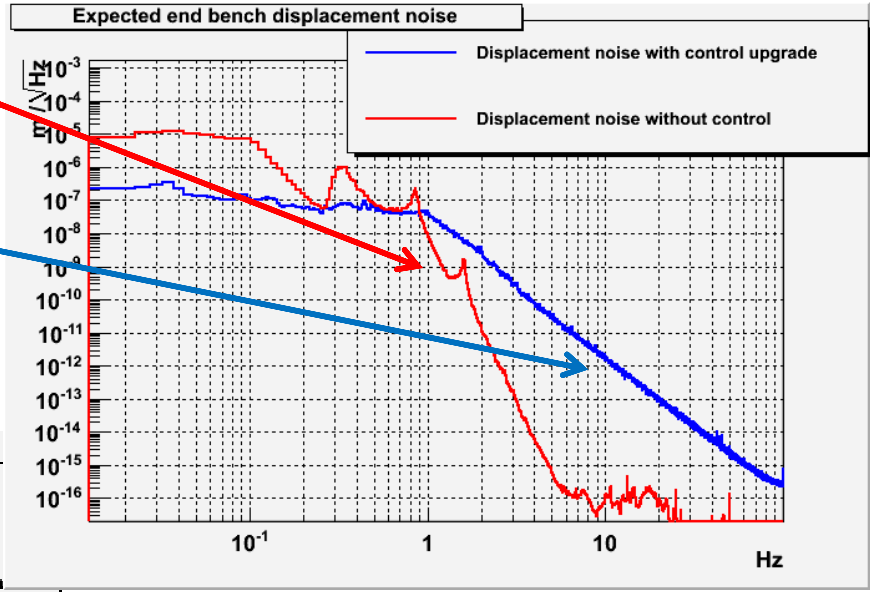


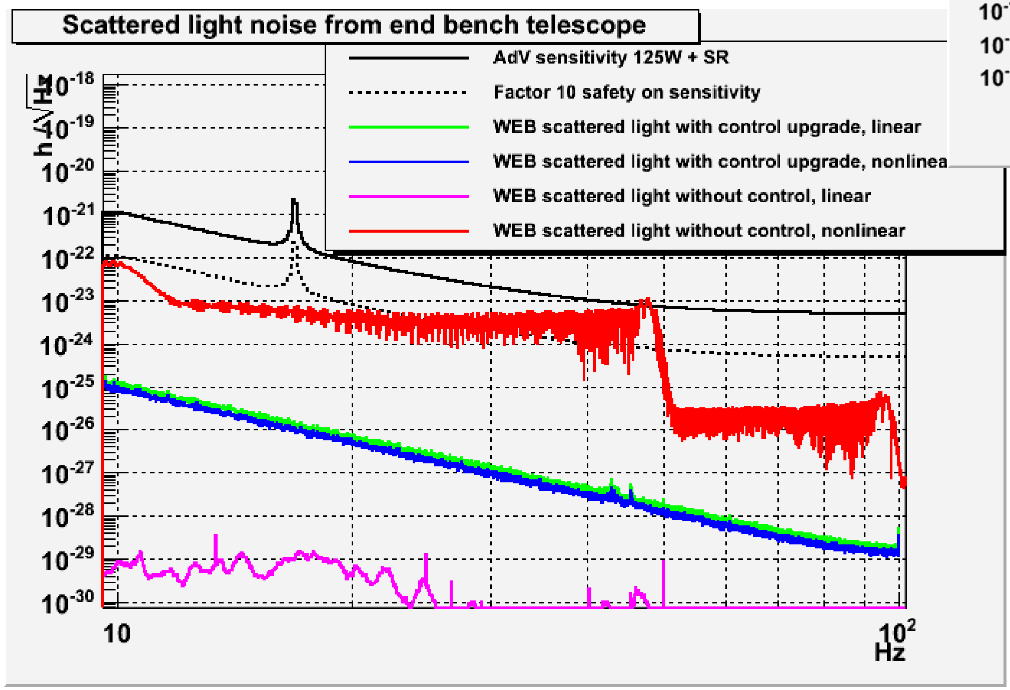
Modification of the optical design as a function of the f_{sc} value

NOISE PROJECTION-END BENCHES

Free bench motion
(using an accelerometer on EB
Virgo+suspension for AdV)

Expected residual bench motion
with control of ETM-EB distance





- Free bench motion induces up-conversion limiting sensitivity
- Control of the EB-End Mirror distance allows to satisfy requirements with a factor 1000 of margin
- The tilt of the small lens is not needed

FUTURE SPACE DETECTOR: LISA

-Three satellites
-Arms 2.5 Mkm
-Inertial masses at arm end
-Noise budget: 10pm/sqrt(Hz) between 0.1 mHz and 1 Hz

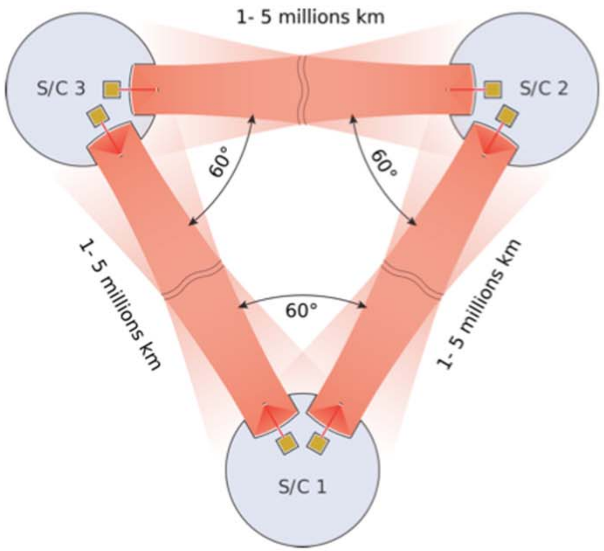


Figure 1 - Configuration de la mission LISA

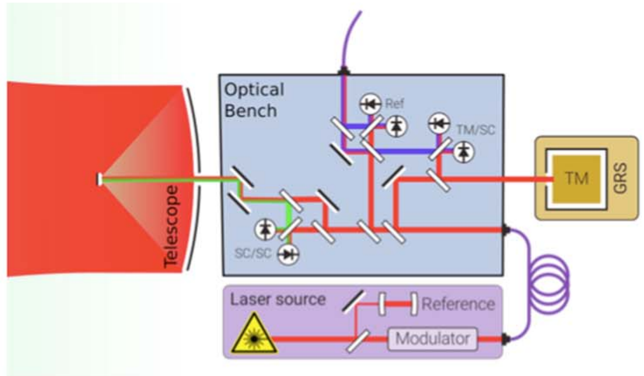


Figure 2 - Schéma d'un instrument de LISA (TM : Test Mass, GRS : Gravitational Reference Sensor)

A critical issue: measure (with the expected resolution) the phase of the Tx (~500pW) with scattered light from the Rx beam (~2W)

Experience from ground based detector with some different points: no Fabry Perot cavities, heterodyne detection, measure between 0.1 mHz and 1 Hz

FIRST STUDIES (1)

ESA ITT 2016-2017: « Metrology Telescope Design for a Gravitational Wave Observatory (MTD) » Thales Italy, Thales France, ARTEMIS/OCA, LMA, INRIM, APC

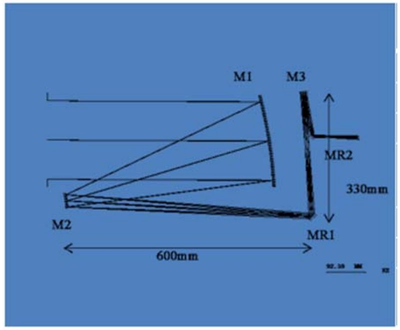
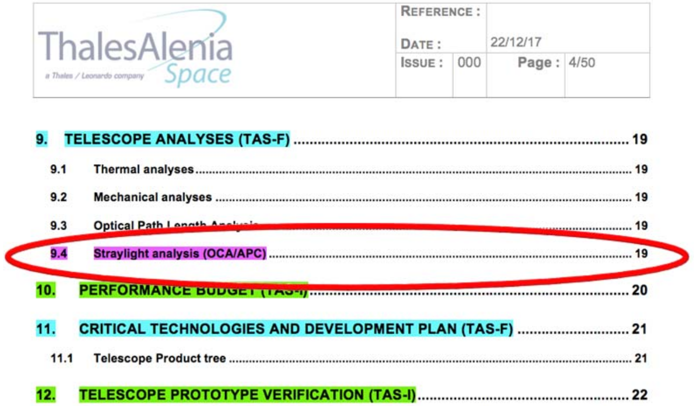


Figure 8



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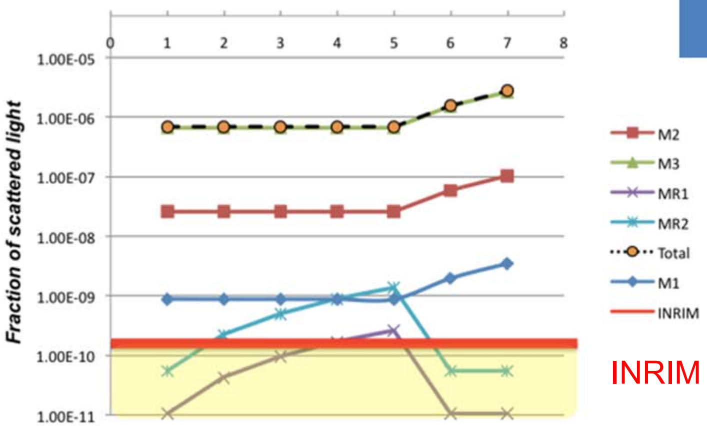
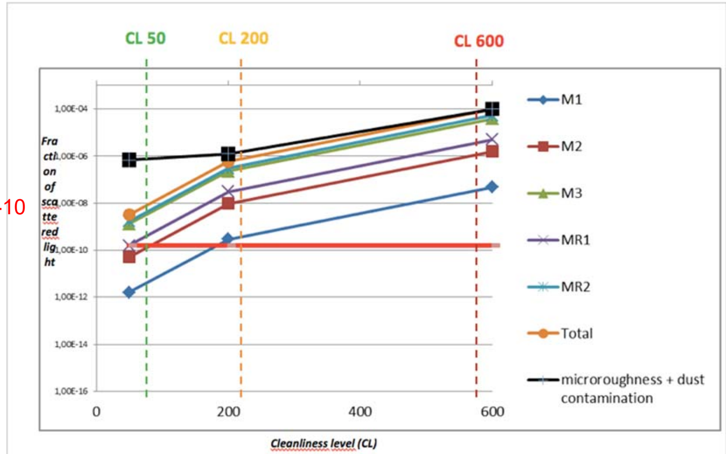


INRIM threshold: 10^{-10}



Several combinations for the TIS have been studied using:
- Super-polished flat mirrors, with micro-roughness from 1 to 5 Å
- Non-flat mirrors, with micro-roughness between 10 and 20 Å

The work continue with the NASA Telescope

FIRST STUDIES (2)

- R&T CNES accepted for two years 2018-2020: APC, ARTEMIS/OCA, LMA

« suite du travail qui vient d'être engagé (action "Mesure de la lumière parasite diffusée pour LISA") sur la mesure de la lumière rétrodiffusée par une optique, par une technique homodyne:
- soit par rétro-injection dans une diode laser , également appelé "self-mixing",
- ou par interférométrie de type Michelson"

WP 0: Gestion de projet et coordination. Leader: APC
WP 1: Modélisation des effets de la lumière diffusée Leader: APC
WP 2: Approvisionnement et caractérisation des éléments parasites *Leader:* LMA
WP 3: Mise en place du banc de test de lumière diffusée *Leader:* ARTEMIS / OCA
WP 4: Réalisation/duplication de l'électronique de lecture (phasemeètre) *Leader:* APC
WP 5: Mesures expérimentales et exploitation des résultats *Leader:* ARTEMIS / OCA

- Working Group « Straylight » for the french AIVT: ARTEMIS/OCA (experimental setup and theoretical analysis), APC (simulations and experimental setup via the R&), Institut Fresnel (measurements and theoretical analysis), LMA (characterization of optical elements and diffusion measurements)

- « Straylight » working group at the consortium level

SUMMARY

- Straylight is a crucial issue for ground based GW detector and space GW detector

- Virgo studies and measurements have been made: use the experience

- Theoretical analysis and simulations are needed to determine the coupling mechanism, the fraction of back-scattered light, the motion of the optics and the projection on the sensitivity

- The analysis allows to define the optics requirements or modify the optical design