Backscattering from Advanced Virgo telescopes

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Backscattered - intro

- The telescopes generate backscattered light, conventionnaly separated in:
  - Direct reflection
  - Diffusion
- The light is:

  1) directly recombined with the main beam (a small fraction)

  2) not directly recombined with the main beam, but hitting secondary targets (vacuum tube, baffles) and then recombined to the main beam (most of the light)

We are interested first in the light directly recombined with the main beam

The main ingredients

- Identify the coupling mechanism
- Compute amount of scattered light
- Compute seismic noise
- Calibrate with the TF of the interferometer → projection of diffused light

Backscattering computation

1) Evaluation of the noise mechanism: i.e, the power variation given by the backscattering

$$\delta P_d(t) = 2\sqrt{P_0}\sqrt{P_d}\sin\left(\frac{4\pi}{\lambda}x(t)\right) \Rightarrow \frac{\delta P_d(t)}{P_0} = 2\sqrt{\frac{P_d}{P_0}}\sin\left(\frac{4\pi}{\lambda}x(t)\right) = 2\sqrt{f_{sc}}\sin\left(\frac{4\pi}{\lambda}x(t)\right)$$

2) Compute f_{sc} (fraction of diffused light) and x(t) (displacement of the diffusing optics)
3) Compute the spectrum of δP/P (f)
4) Calibrate the spectrum with the calibration factor a(f)=h/(δP/P_{OG})

(as done for instance in the note VIR-NOT-0179D-11, by G.Vajente)

K's factors in general valid only in linearized case and in general frequency dependent. In the following we consider linearized case at 10 Hz (some confusion in some previous documents)

Coupling mechanisms

Coupling for detection/1

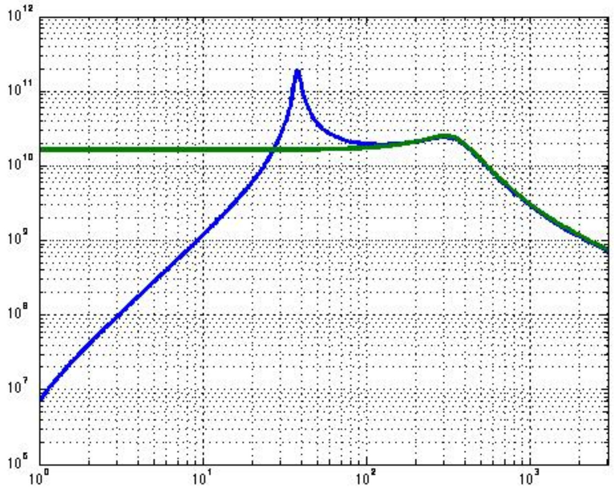
power modulation $$\delta P_d(t) = 2\sqrt{P_0}\sqrt{P_d}\,\sin\big(\varphi(t)\big)$$

$$frequency - domain \Rightarrow \delta P_d(f) = 2\sqrt{P_0}\sqrt{P_d}\,\varphi(f) = \delta P_d(f) = 2\sqrt{P_0}\sqrt{P_d}\,\frac{4\pi}{\lambda}x(f)$$

For a gravitational wave, (low frequency)

$$\delta P_{OG} = h\cdot\left(2P\frac{L}{l_{offset}}\frac{f^2}{f_{opt}{}^2 - f^2}\right) = \delta L\cdot\left(2P\frac{1}{l_{offset}}\frac{f^2}{f_{opt}{}^2 - f^2}\right)$$

Where: f_{opt}= optical spring frequency = 40 Hz



$$\frac{\delta P_{OG}}{\delta L} = \left(\frac{2\cdot 0.1W}{10^{-11}m}\frac{f^2}{f_{opt}{}^2 - f^2}\right) = 2\cdot 10^{10}\times\frac{f^2}{f_{opt}{}^2 - f^2}$$

Coupling for detection/2

- Equivalent strain:

$$h = \frac{2\sqrt{P_0}\sqrt{P_d}\,\frac{4\pi}{\lambda}x}{\left(2P_0\frac{L}{l_{offset}}\frac{f^2}{f_{opt}^2 - f^2}\right)} = \sqrt{\frac{P_0}{P_d}}\frac{l_{offset}}{L}\frac{f_{opt}^2 - f^2}{f^2}\frac{4\pi}{\lambda}x$$

$$\sqrt{\frac{P_d}{P_0}} = \sqrt{f_{sc}} \quad \rightarrow \quad h = \sqrt{f_{sc}}\frac{l_{offset}}{L}\frac{f_{opt}^2 - f^2}{f^2}\frac{4\pi}{\lambda}x = \sqrt{f_{sc}}K_{\det}\varphi = G_{\det}\frac{4\pi}{\lambda}x$$

Where $K_{\det} = \frac{l_{offset}}{L}\frac{f_{opt}^2 - f^2}{f^2}$

With $l_{offsett}$ = 10^{-11} m and L=3 km $\quad K_{\det} = 3\cdot 10^{-15}\frac{f_{opt}^2 - f^2}{f^2}$

Note: K_{det} bigger by factor 15 at 10 Hz wrt formula used in the past

Coupling for injection/1

Traditional path: frequency noise

Freq domain, linearized case

$$h = \sqrt{f_{sc}}\,\frac{2\pi f}{G_{SSFS}}\,\frac{CMRF}{f_{laser}}\,\frac{4\pi}{\lambda}\,x = \sqrt{f_{sc}}\,K_{inj}\,\frac{4\pi}{\lambda}\,x$$

Where f_{sc} is the fraction of the input be m (125 W) backscattered and recombined with the interferometer mode

Remarks:

- In the formula reported in VIR-NOT-070A-08 2xpi missing
- Confusion between time domain and frequency domain in some previous estimations

@10 Hz, with CMRF=10^{-2}, $G_{SSFS}=10^{7}$ → $K_{inj}=2\times10^{-22}$

Coupling for injection/2

Diffused light changes also the interferometer input power

$$\delta P_d(t) = 2\sqrt{P_0}\sqrt{P_d}\sin(\varphi(t))$$

From the specifications about the RIN at 10 Hz after the interferometer input we have

$$h/10 = 4\cdot 10^{-9} \times \alpha \Rightarrow \alpha = 2.5\cdot 10^{-14}$$

$$\Rightarrow h = 2.5\cdot 10^{-14} \times \frac{\delta P_d}{P}$$

$$h = 5\cdot 10^{-14}\sqrt{f_{sc}}\sin(\varphi) \Rightarrow K_{inj} = 5\cdot 10^{-14}$$

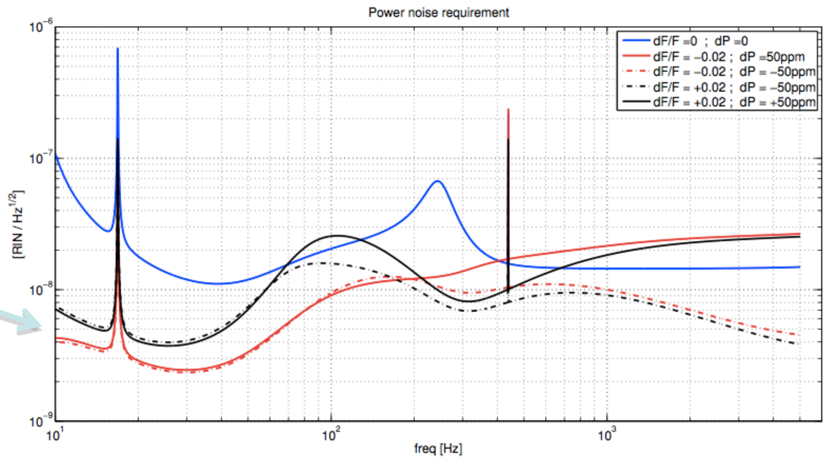
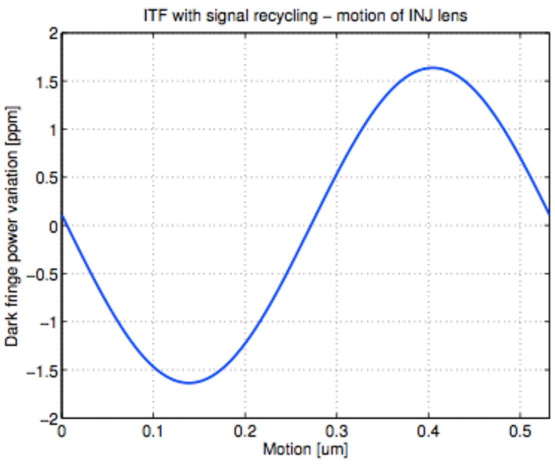


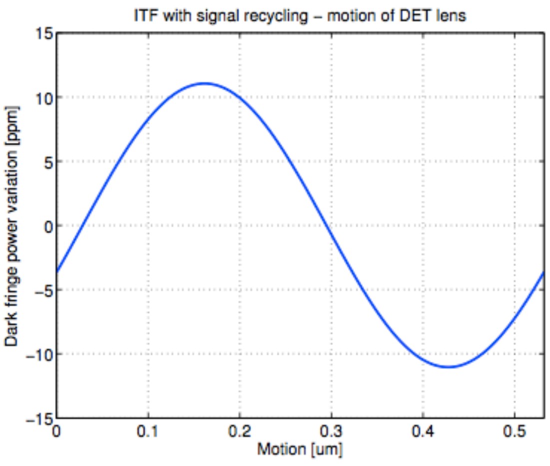
Figure 8.7: Dual recycled full power configuration, frequency and power noise requirements with a safety factor of ten used to draw the requirements from nominal sensitivity. Different values of finesse and loss asymmetries are used. Top: laser frequency noise at interferometer input. Bottom: laser intensity noise at the interferometer input. Blue curve: no defects. Red curves: dF/F = -2%; black curves: dF/F = +2%. Solid curves: dP = +50 ppm, dashed curves: dP = -50 ppm.

Injection coupling vs G. Vajente simulations

- Vajente's simulations (VIR-NOT-0179D-11)

$$G \cong 10^{-20} = \sqrt{f_{sc}} K_{inj} \Rightarrow K_{inj} = \frac{G}{\sqrt{f_{sc}}} = \frac{10^{-20}}{\sqrt{10^{-11}}} \cong 3 \cdot 10^{-15}$$





- DET ~ 7 x INJ

Coupling for End benches

Diffused light produces a change in the phase inside the Fabry-Perot cavities which mimic a gravitational-wave

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

Where f_{sc} is the fraction of the light transmitted by the cavity, backscattered and recombined with the arm cavity mode

Remarks:

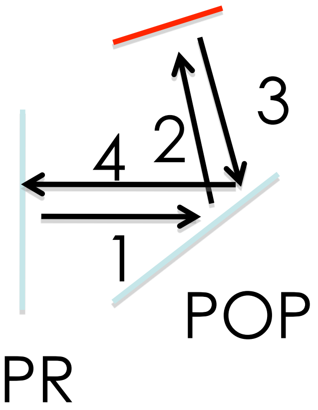
- K_{end} not correct in the previous Virgo notes
- In this case the transfer function for the diffused light and for the OG are the same

For T=1 ppm, L=3 km → $K_{end} = 2.5 \times 10^{-17}$

Coupling for the pick-off / power noise

$$\delta P_d(t) = 2\sqrt{P_0}\sqrt{P_d}\,\sin(\varphi(t))$$

- Similar computation done for K_{inj} $\quad h = 2.5\cdot 10^{-14} \times \frac{\delta P_d}{P}$



(I consider here the same specs for the RIN used for the input beam)

- $P_0 = P_{rec}$
- $P_d = P_{rec} \times R_{POP} \times f_{sc} \times R_{pop}$

$$\Rightarrow \frac{\delta P_d}{p} = 2R_{POP}\sqrt{f_{sc}}\varphi$$

- Power noise path $\quad h = 5\cdot 10^{-14} R_{POP}\sqrt{f_{sc}}\varphi \Rightarrow K_{pop} = 5\cdot 10^{-14}$

- Frequency noise path reduced by SSFS gain (same as inj)

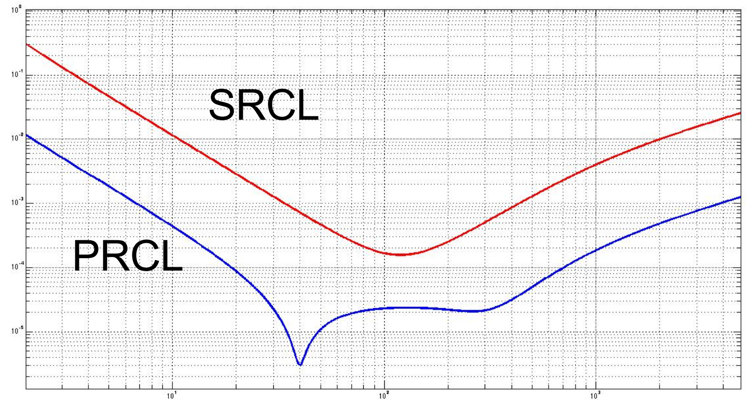
Coupling for the pick-off / PRCL

- Diffused light produces a phase variation inside the recycling cavity (PRCL)
- Computation analogous to K_{end}

$$h = \frac{DARM}{L} = \frac{PRCL \cdot TF(PRCL/DARM)}{L}$$

$$PRCL = R_{POP}\sqrt{f_{sc}}\,\frac{\lambda}{4\pi}\sin(\varphi)$$

Coumpling PRCL→ DARM



$$K_{POP} = R_{POP}\frac{\lambda}{4\pi}\frac{1}{L}TF(PRCL/DARM) \Rightarrow K_{pop}(10Hz) \cong 10^{-18}$$

Couplings: summary

• Recomputation for INJ/DET/END, some changes wrt prevision estimations and big change for INJ (several orders of magnitudes)
• Computed path for pick-off
• Removed some confusion in some previous computations: time domain versus frequency domain → use method used in VIR-NOT-0179D-11
• Order of magnitude for couplings (values of K for linearized case at 10 Hz)
• Similar coeff for INJ/DET reinforces the use of same telescope strategy
• Similar coeff for END/POP justifies the use of same telescope configuration and same optics

$$K_{\mathrm{det}} = 5 \cdot 10^{-14}$$

$$K_{inj} = 5 \cdot 10^{-14}$$

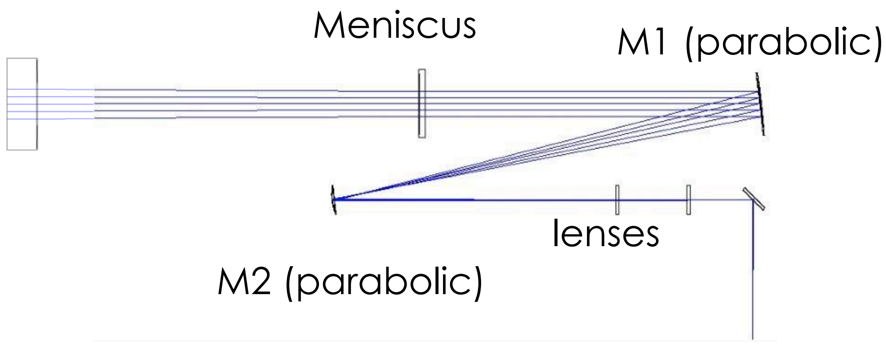
$$K_{end} = 2.5 \cdot 10^{-17}$$

$$K_{pop} = 5 \cdot 10^{-18}$$

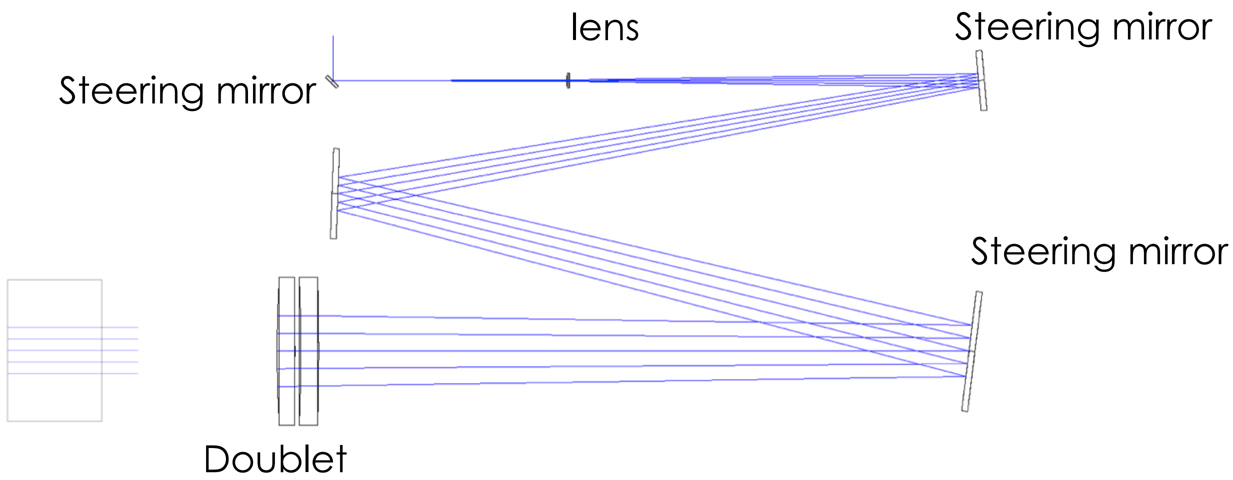
Fraction of diffused light by telescope optics

Optical schemes

- INJECTION/DETECTION
    - 1 superpolished meniscus lens
    - 2 parabolic mirrors
    - 2 superpolished lenses

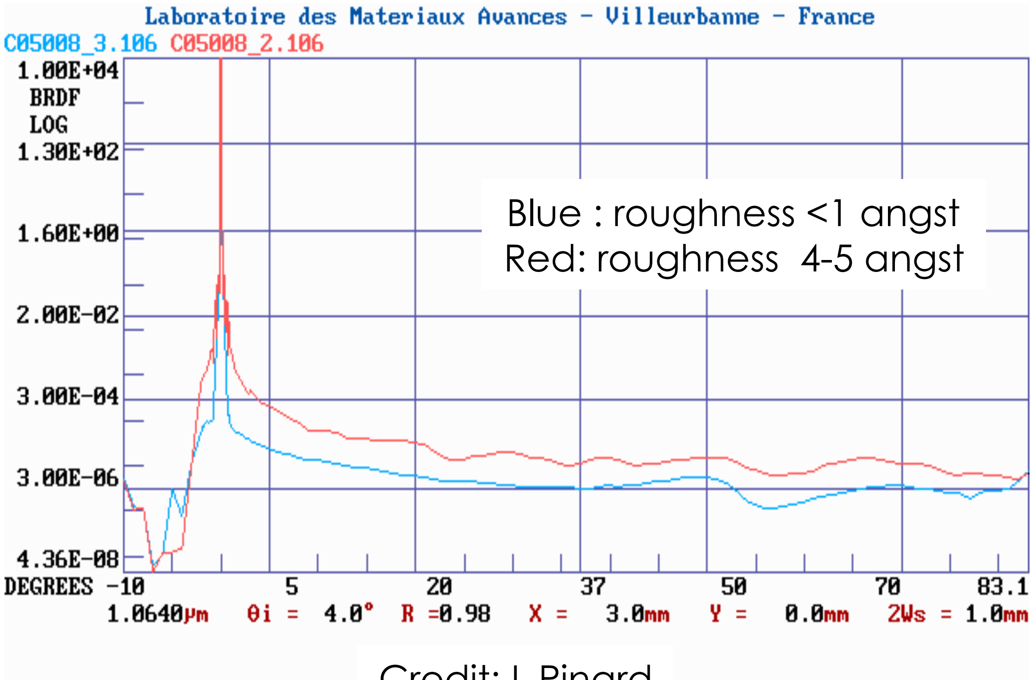


- END BENCHES / PICK-OFF
    - 1 superpolished doublet
    - 3 superpolished flat steering mirrors
    - 1 superpolished 2 inch lens



Non normal incidence elements (parabolic and steering mirrors): hypothesis

We assume a Lambertian distribution (BRDF = constant → TIS/π)



Credit: L.Pinard

Hypothesis (some numbers)

- Superpolished (~ 3 angst)
  - TIS=10 ppm, BRDF=3x10^{-6} strd^{-1}
- Parabolic (roughness ~ 1 nm)
  - TIS=150 ppm, BRDF= 50x50^{-6} strd^{-1}

Non normal incidence elements: method

• Light recombined = BRDF * (total solid angle of recombined light)

• Computation of the solid angle of the recombined light is made via geometrical optics, through a Matlab base code (ADOC = *APC Diffusion of Optics Code*)

• ADOC propagates optical rays over the optical system (telescope and interferometer with their aperture)

• Various preliminary checks with Zemax made

• ADOC available for people interested

Superpolished mirrors (at normal incidence)

$$\Psi(x,y) = e^{2ikf(x,y)}\phi(x,y)$$ ← Beam reflected by Perfect mirror (with curvature)

With: $$\left|2kf(x,y)\right| = \left|\frac{4\pi}{\lambda} f(x,y)\right| << 1$$

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

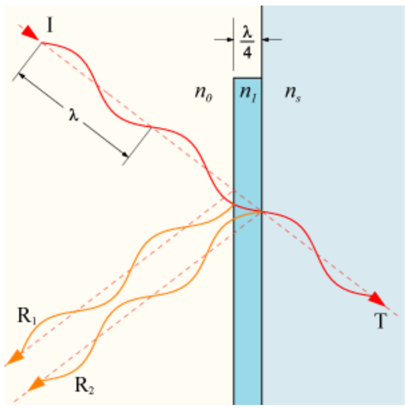
For mirrors verifying the condition above
The recoupled light is given by the overlap integral of between the ITF mode and the reflected beam

Some back scattering theory: Vinet, Brisson, Braccini al PRD, 54, 2 (1996) *Scattered light noise in gravitational wave interferometric detectors: Coherent effects*

The AR coating

AR simple model

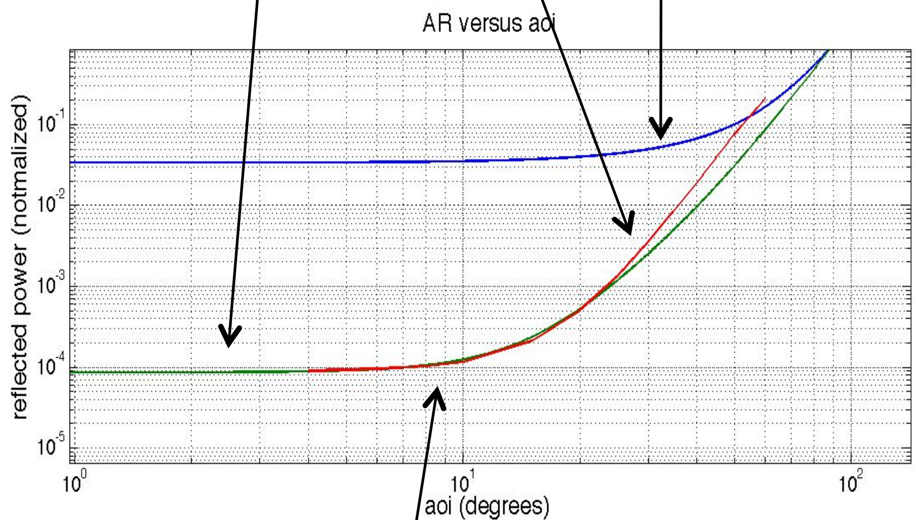
- 2 layers
- Interference between two waves



No AR

AR Simple model

measurements



The real AR coating

- AR coating by LMA ~ 100 ppm (Conservative, L.Pinard)
- 4 layers :Tantala (H), Silica (L), Tantala (H), Silica (L)
- AR coating constant whitin ~ 10 deg angle of incidence (L.Pinard)

BRDF measurements of AR coated lens

• No measurement (at our knowledge) of BRDF at small anglesf on AR components

• Measurements at < 1 deg very difficult, but BRDF measured at ~ 5 deg could already give some indications

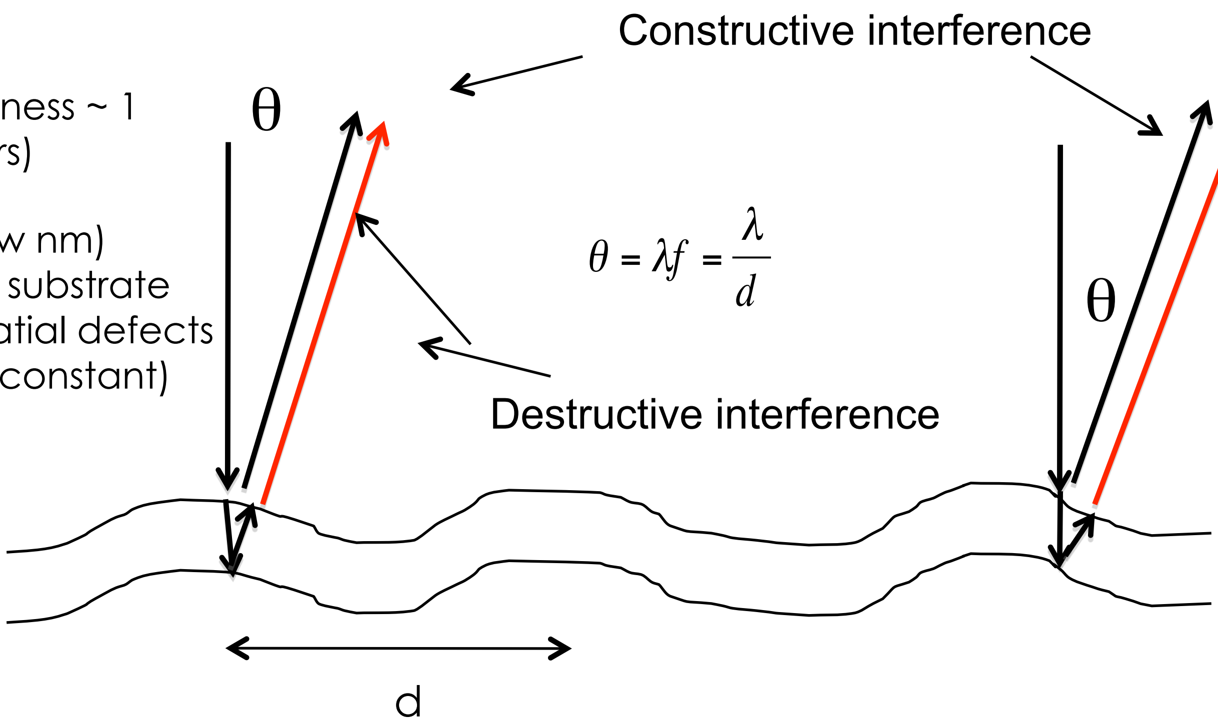
• Same BRDF of AR sample already measured by Lyon, but we need a measurement on a sample with 2 AR faces and same surface quality needed (to avoid the contamination by the diffusion of the 2^{nd} face)

• Discussion on going with Laurent Pinard at LMA to see if it's possible to perform this measurement

AR coating and diffraction

- coating thickness ~ 1 micron (4 layers)

- defects (a few nm) dominated by substrate large scale spatial defects (coat tickness constant)



$$\theta = \lambda f = \frac{\lambda}{d}$$

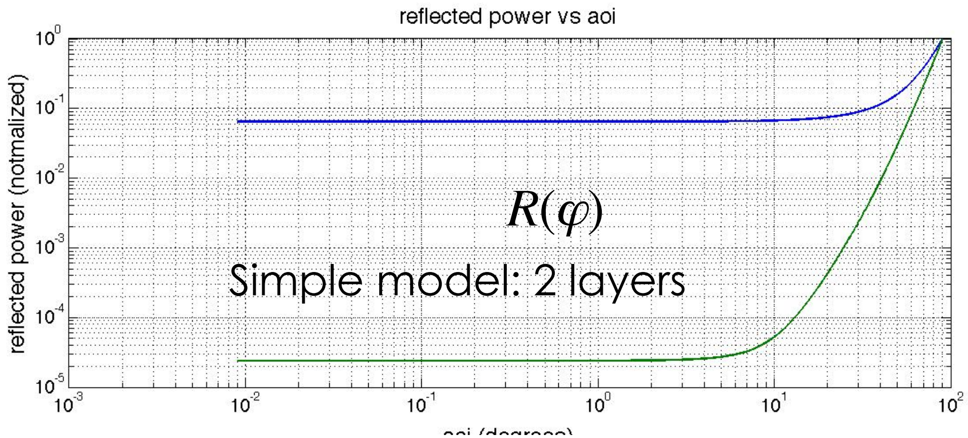
Model:

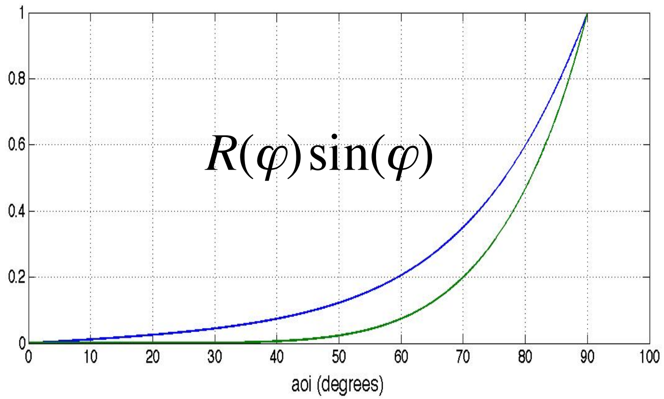
- Waves reflected by various layers experience destructive interference for scattering angles < a few degrees
- Diffracted waves are the sum of the waves reflected by the layers

→ Diffracted waves see same (constant) reflectivity of the AR coating for angles < a few degrees

AR and TIS

- Measurements by B. Canuel (WE window)
  - Reflectivity 6.5 % → 20 ppm
  - TIS 100 ppm → 20 ppm
- Model: $TIS = \int R(\varphi) BRDF \cdot d\Omega = BRDF \int R(\varphi) \cdot d\Omega$



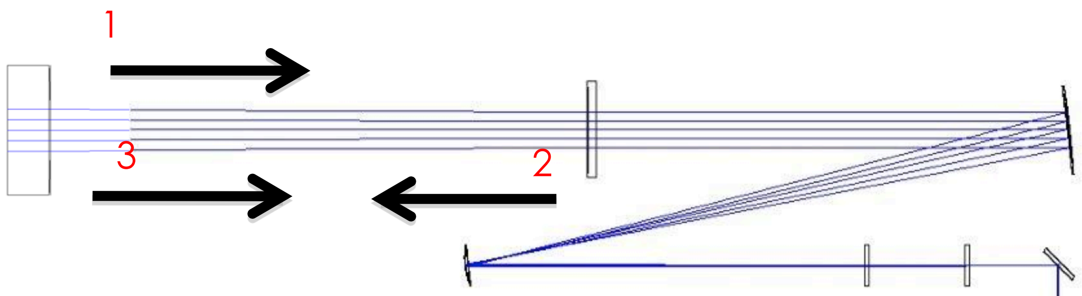


TIS (6.5%) / TIS(20 ppm) = 0.65 → TIS weakly affected by the AR

Dark fringe telescope

How to compute the fraction of scattered light for DET

P_0 (interferometer TEM00 mode) and P_d should interfere (same mode)

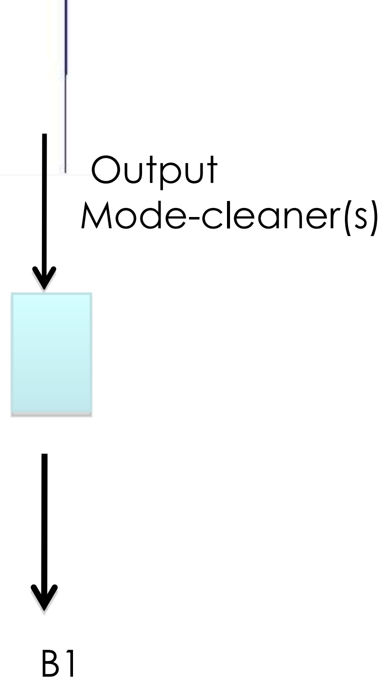


- output of the interfereometer (P_1) – we suppose 1 W in the TEM00 (in reality we don't know the mode composition)

- output of the diffusing element (P_2)

- reflection by SR (P_3) – we suppose that all the light is reflected by SR (conservative estimate)

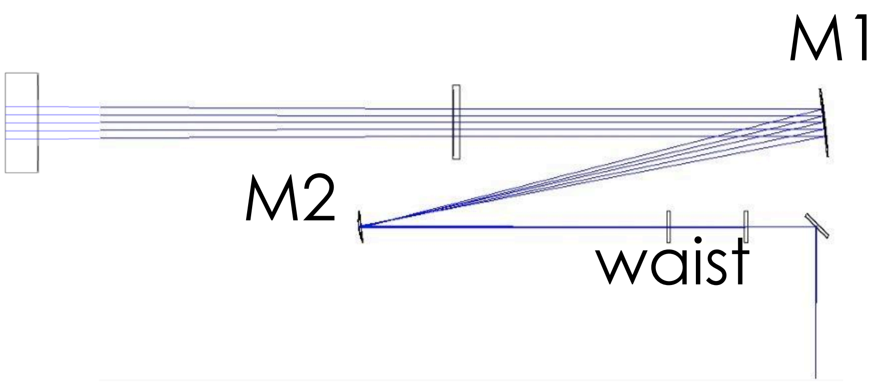
- fraction of P_3 superspposed to P_0
  - Method A) We propagate P_2 in the arm cavities for several roundtips (as in VIR-NOT-0375A-10)
  - Method B) We propagate P_2 through the telescopes and the OMCs (on going) – **on going**



ADOC results, parabolic mirrors DET and INJ

Elements	w [m]	f_{sc} ADOC	f_{sc} ZEMAX
M1 (3km)	22e-3	1.7e-8	2.6e-8
M1 (4AR)	22e-3	**2.2e-9**	
M2 (3km)	1.37e-3	4.2e-6	4.2e-8
M2 (4AR)	1.37e-3	**6.0e-7**	
At waist (3 km)	1.3e-3	6.9e-6	6.1e-6
At waist(4AR)	1.3e-3	**5.5e-7**	

TIS=1



Conclusion for parabolic mirrors

- Good agreement between ADOC and Zemax (whitin a factor 2) for propagation at 3 km
- ADOC converges for N=4 roundtrip
- Zemax does not converge (already seen by Genin et al., not understood)

- f_{sc} (M1) = 2x10^{-9} x 150 ppm = 3 x10^{-13}
- f_{sc} (M2) = 6x10^{-7} x 150 ppm = 9x10^{-11}

Remark:

- f_{sc} (element at waist after the parabolic telescope, for instance Faraday isolator) = 6x10^{-7}* TIS

- If we take the LIGO estimation (see LIGO T080210-00) :

BRDF= 5x10^{-4} strd^{-1} → TIS=1500 ppm → f_{sc} = 6x10^{-7} x 1500 ppm = 9x10^{-10}

- Scattering by Faraday isolator components non negligible! (TBC)

Results vs divergency formula

« *Divergency* formula » (integration in the divergency cone), traditionnaly used:

$$f_{sc} = BRDF \cdot \pi\vartheta_\infty^2 = \frac{TIS}{\pi} \cdot \pi\left(\frac{\lambda}{\pi\ w}\right)^2 = TIS\frac{\lambda^{\ 2}}{\pi w^2}$$

f_{SC} (M2, or waist after the telescope), with TIS=1

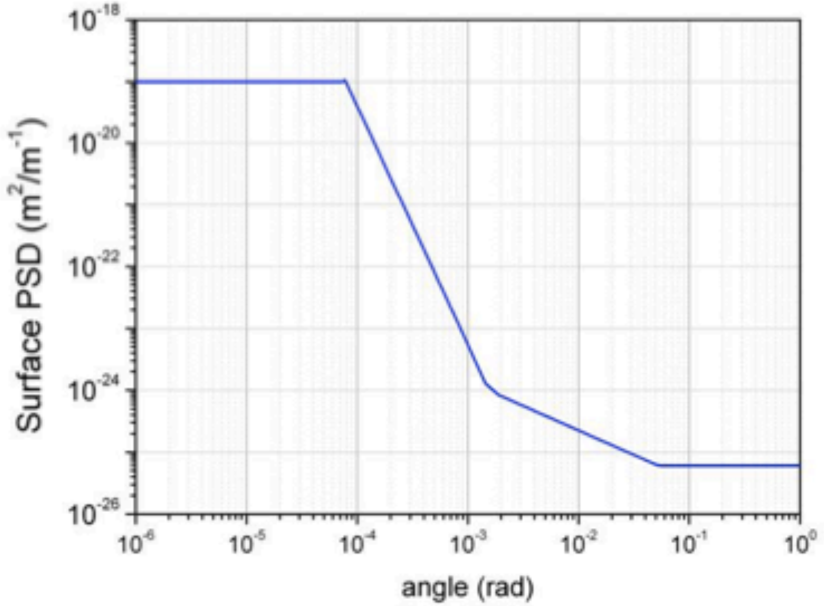
divergency formula: $2X10^{-7}$

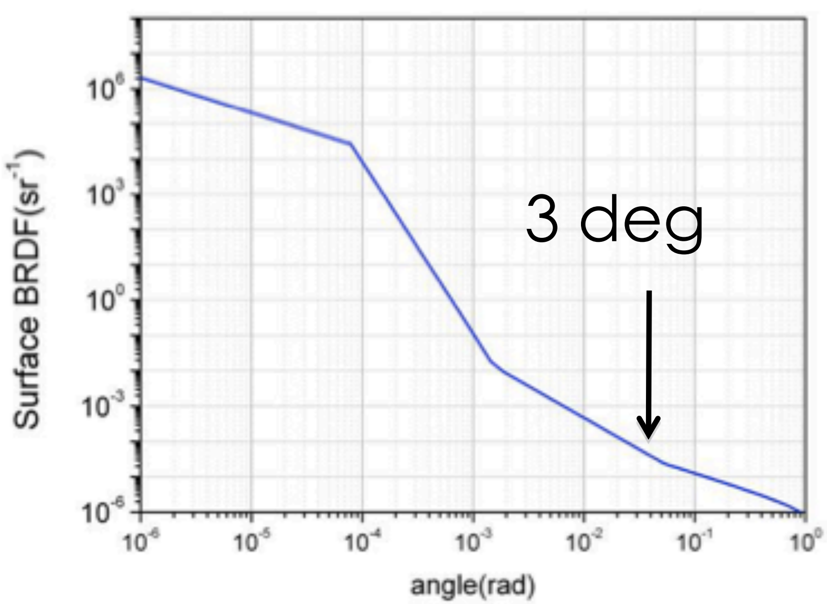
ADOC: $6\ x10^{-7}$

- ADOC gives 3 times the value of the divergency formula
- Remarks: for ADOC the aperture matters, not for divergency formula

Meniscus lens – PSD and BRDF

Technical Desing Report





$$diffusion = 4k^2\sigma^2 = \frac{16\pi^2\sigma^2}{\lambda^2} = 140\,ppm\left(\frac{\sigma}{1nm}\right)^2$$

- RMS ~ 3 nm
- Total losses ~ 1300 ppm
- Losses mainly due to large scale defects
- Losses for angles >1 deg = a few ppm

Meniscus lens

- Scattering for angles < 3 deg, see the AR coating

$$f_{sc}^{first} \cong \left|\left\langle \phi(x,y) \middle| \phi_0(x,y) \right\rangle\right|^2 \times R_{AR} = 3\cdot 10^{-7} \times 10^{-4} = 3\cdot 10^{-11}$$

$$f_{sc}^{second} \cong \left|\left\langle \phi(x,y) \middle| \phi_0(x,y) \right\rangle\right|^2 \times R_{AR} = 4\cdot 10^{-6} \times 10^{-4} = 4\cdot 10^{-10}$$

- Scattering for angles > 1 deg does not contribute to the $f_{sc,}$ because of the geometry of the system → light is outside the apertures (simple estimation: 5 cm / 5 m = 10 microrad, ADOC confirmation)

- Remarks:

    - Total backscattering does not depend on the RMS, if RMS dominated by large scale defects and for RMS << λ
    - The important factor is R_{AR}

Non uniform diffusion in ADOC

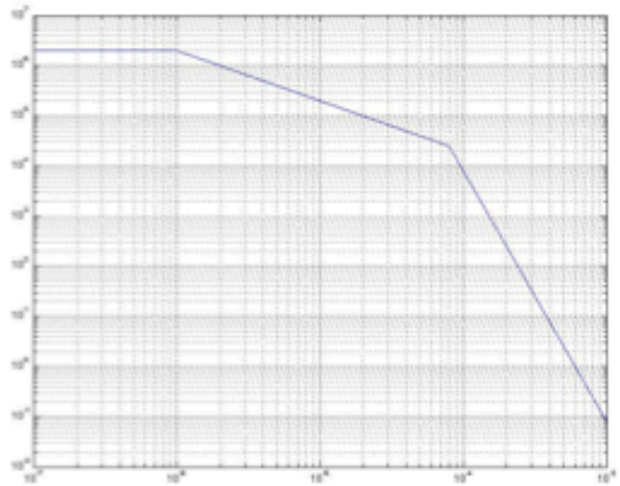
Meniscus lens – side 1

f_{sc}(AR=1) = 2×10^{-9}

Diffusion part of the backscattering =
$2\times10^{-9}\times10^{-4} = 2\times10^{-13}$
(direct reflection is dominant)

Remark: 2×10^{-9} =1.3 e-6 * total scattering (1300 ppm)

(overlap integral = 3 e-7)



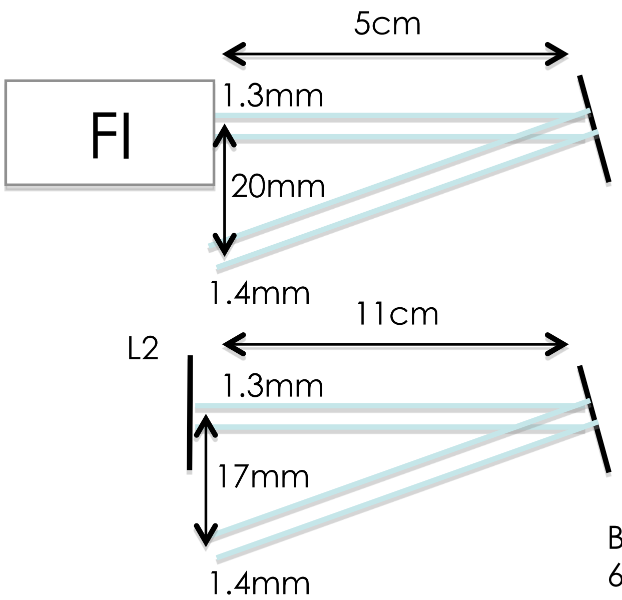
Diffusion law implemented in ADOC

Small lenses

- Beam is smaller and collimated on the 2 inch lenses → overlap integral very high

$$f_{sc}^{second} \cong \left| \langle \phi(x,y) | \phi_0(x,y) \rangle \right|^2 \times R_{AR} \times T_{faraday} = 10^{-1} \times 10^{-4} \times 10^{-2} = 10^{-7}$$

- Remove the reflection and main component of the diffusion by tilting the lenses

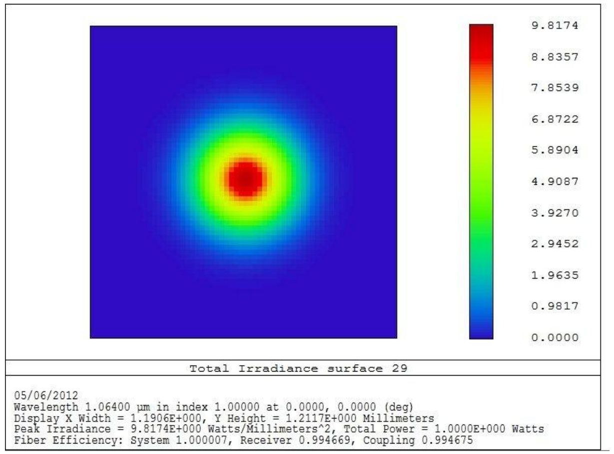


L2 – RoC 2.05m

Baffle behind FI to dump the reflection
6 x w_1 + 6 x w_2 = 16.2mm ≈ 20mm
Tilt L2 = 11°

L3 – RoC 1.65m

Baffle behind L2 to dump the reflection
6 x w_1 + 6 x w_2 = 16.2mm ≈ 17mm
Tilt L2 = 4.3° v



Coupling efficiency = 0.995

Fraction of diffused ligth: summary for detection

- Fraction of backscattered light (for 1 W ITF output)

- f_{sc} (M1) = $3 x10^{-13}$ (TIS=150 ppm)
- f_{sc} (M2) = $9x10^{-11}$ (TIS=150 ppm)
- f_{sc} (meniscus 1st face)= $3 x10^{-11}$ (R_{AR}=100 ppm)
- f_{sc} (meniscus 2nd face)= $4x10^{-10}$ (R_{AR}=100 ppm)
- f_{sc} (lenses tilted after the Faraday) = $6x10^{-7}$ x 10 ppm x 10^{-2} = $9x10^{-13}$

$$\sqrt{\frac{P_d}{P_0}} = \sqrt{\frac{f_{sc}}{0.1}}$$

- Noise add coherently → $\frac{\delta P_d(t)}{P_0} = \sum \sqrt{\frac{P_d}{0.1}} \times \sin\left(\frac{4\pi}{\lambda} x(t)\right) \cong \sqrt{4 \cdot 10^{-9}} \times \sin\left(\frac{4\pi}{\lambda} x(t)\right)$

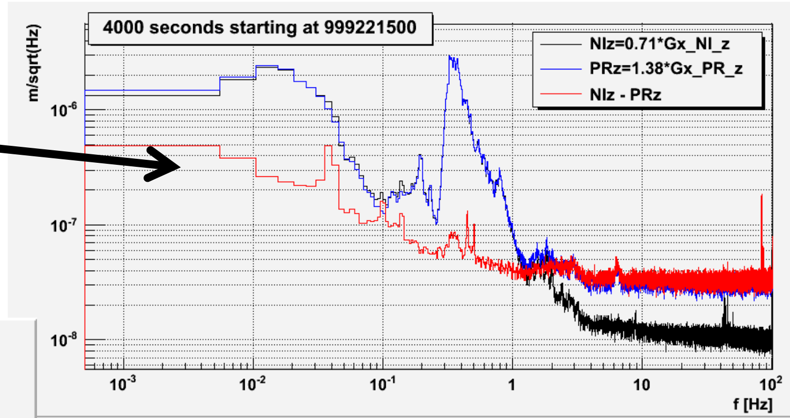
- Remark:
    - this is the light directly recoupled with the main beam (not secondary scattering from baffles, tubes)

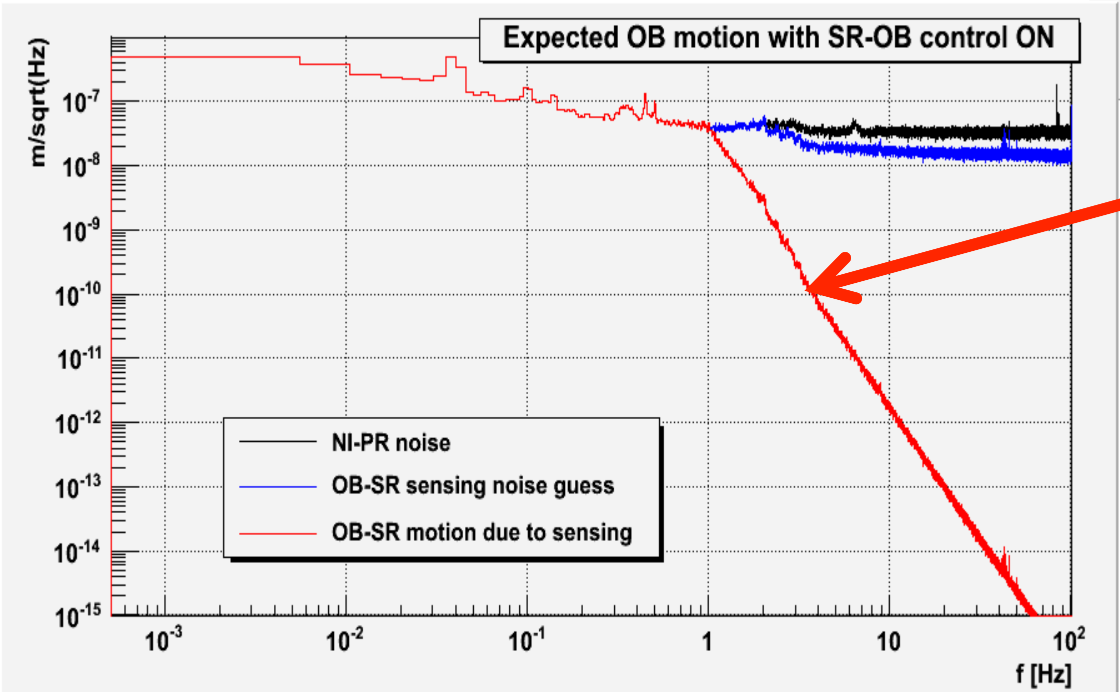
Estimation of the seismic noise for detection bench

Expectation: control of the relative distance between SR and the bench using error signals provided by local controls (see VIR-0132A-12)

Mirror motion as measured by the local controls, when ITF is locked

⇒ Substraction (NI_z – PR_z) is sensitive to length fluctuations of a few 0.1 μm



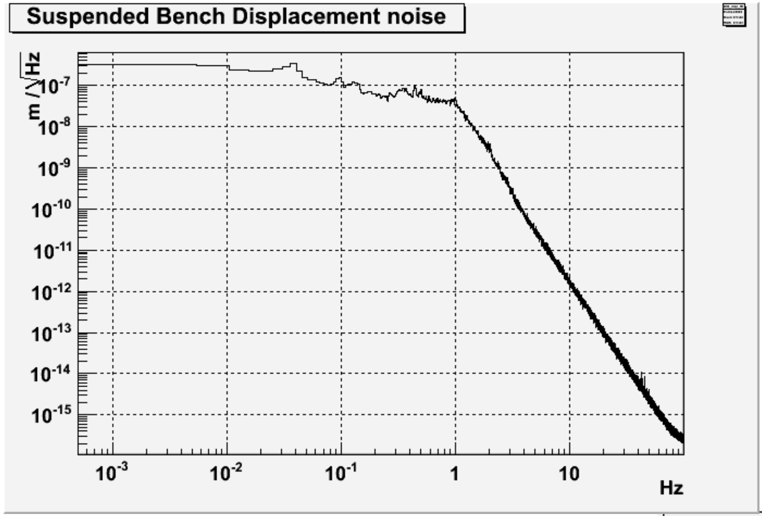


Assumptions used for OB motion:

- **f < 1Hz:**
  Residual motion ≈ NI - PR

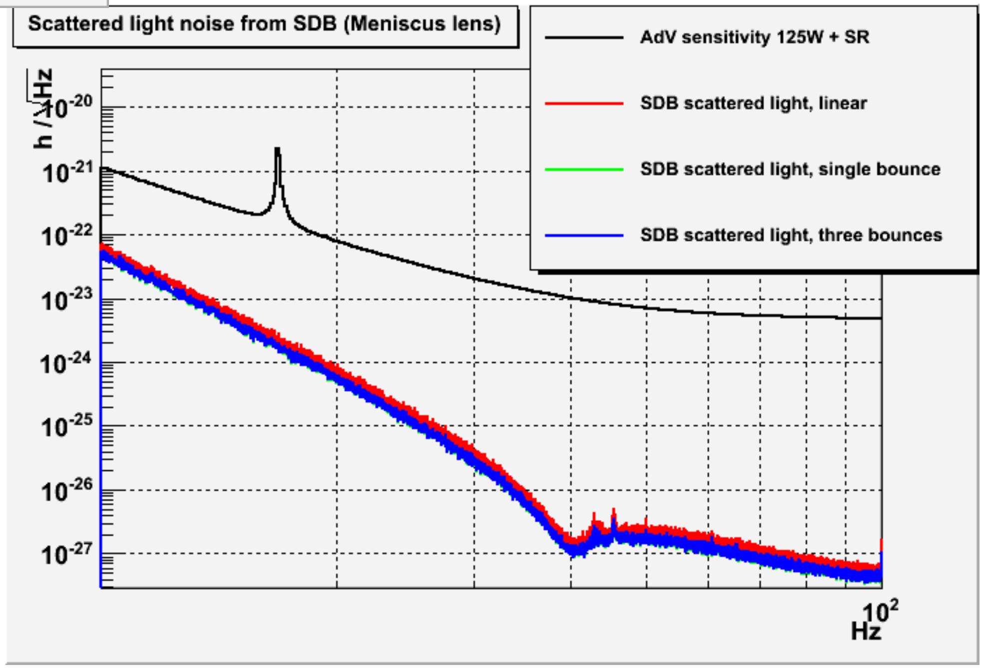
- **f > 1Hz:**
  Dominated by control noise
  Attenuated in $1/f^4$
  (control filter + pendulum TF)

Noise projections



Detection bench displacement with SR-DET *local control locking*

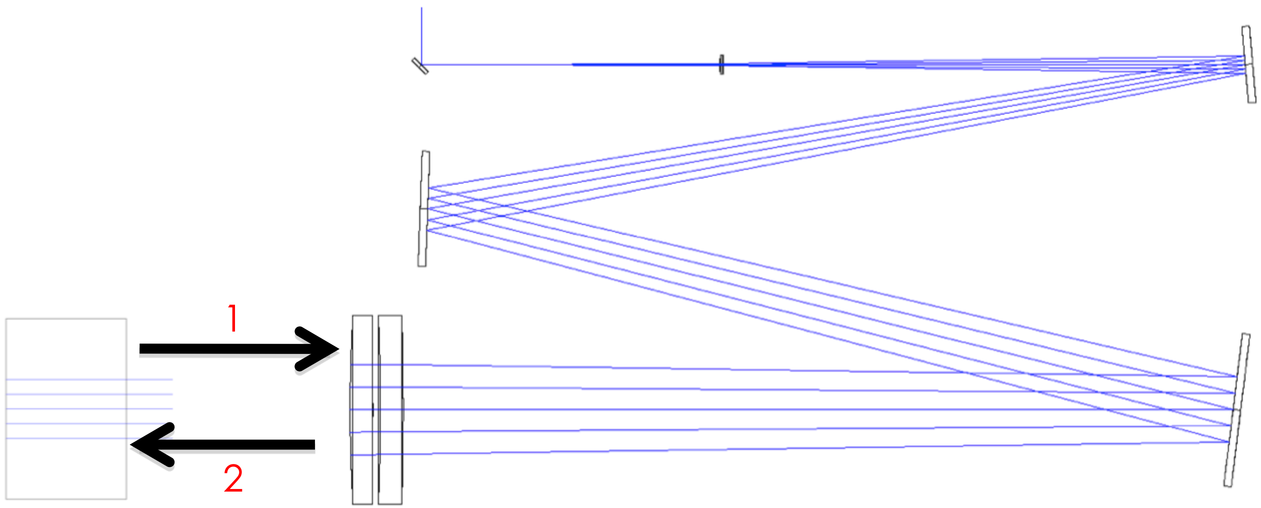
Equivalent strain



End bench telescopes

How to compute the fraction of scattered light for EB

P_0 (interferometer TEM00 mode) and P_d should interfere (same mode)



- output of the interferometer (P_1)
-
- output of the diffusing element (P_2)
- fraction of P_2 superposed to P_0
- we propagate P_2 in the arm cavities for several roundtrips (as in VIR-NOT-0375A-10)

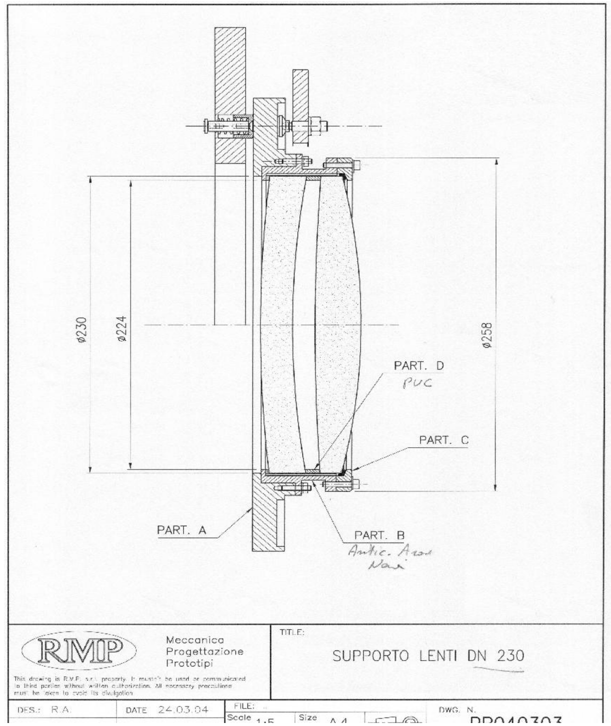
End bench doublets

- Doublet surface quality and AR are not know (written traces not found)

- Doublet will be sent to LMA before end of June to be measured

- For the moment:

  - $R_{AR,}$ we assume R=0.5% (echanges with E.Genin)
  - bakscattering limited by reflection - same hypothesis of meniscus



$$diffusion = 4k^2\sigma^2 = \frac{16\pi^2\sigma^2}{\lambda^2} = 140\,ppm\left(\frac{\sigma}{1nm}\right)^2$$

Doublet

- Scattering for angles < a few deg (diffusion given by large scale defects)

$$f_{sc}^{first} \cong \left|\left\langle \phi(x,y) \middle| \phi_0(x,y) \right\rangle\right|^2 \times R_{AR} = 5\cdot 10^{-8} \times 5\cdot 10^{-3} = 2.5\cdot 10^{-10}$$

$$f_{sc}^{\sec ond} \cong \left|\left\langle \phi(x,y) \middle| \phi_0(x,y) \right\rangle\right|^2 \times R_{AR} = 5\cdot 10^{-8} \times 5\cdot 10^{-3} = 2.5\cdot 10^{-10}$$

$$f_{sc}^{third} \cong \left|\left\langle \phi(x,y) \middle| \phi_0(x,y) \right\rangle\right|^2 \times R_{AR} = 3\cdot 10^{-8} \times 5\cdot 10^{-3} = 1.5\cdot 10^{-10}$$

$$f_{sc}^{fourth} \cong \left|\left\langle \phi(x,y) \middle| \phi_0(x,y) \right\rangle\right|^2 \times R_{AR} = 5\cdot 10^{-8} \times 5\cdot 10^{-3} = 2.5\cdot 10^{-10}$$

• Scattering for angles > a few deg does not contribute to the $f_{sc,}$because of the geometry of the system → light is outside the apertures

Non uniform doublet diffusion in ADOC

Doublet– side 1

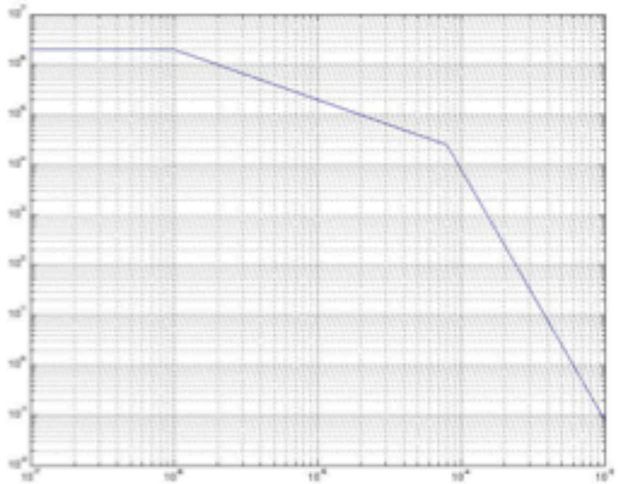
f_{sc}(AR=1) = 4×10^{-10}

f_{sc} (AR=0.5%) = $4\times10^{-10} \times 5\ 10^{-3} = 2\times10^{-12}$

(reflection is dominant, even if total scattering is much higher)

Remark: 4×10^{-10}= 3 e-7 * total scattering (1300 ppm) (overlap integral = 5 e-8)

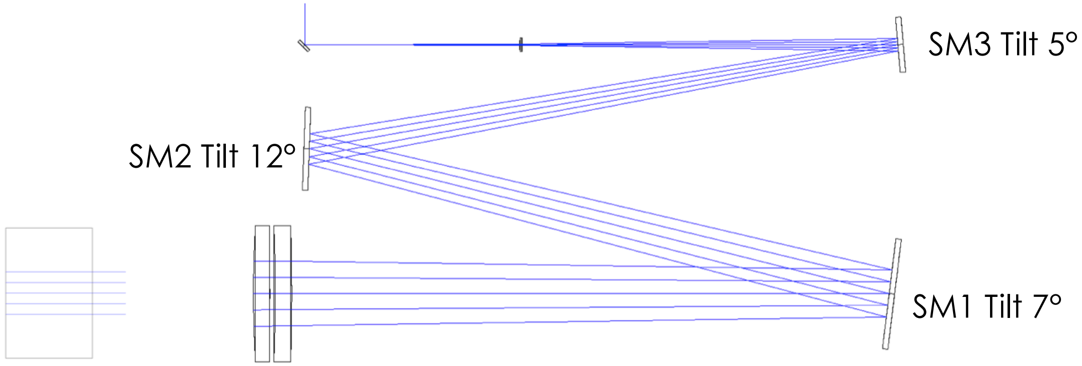
For the moment same law used for meniscus lens



Same diffusion law used for detection

Steering mirrors

• Lambertian diffusion (components not at normal incidence), ADOC simulation



• f_{sc} (SM1) = $6x10^{-10}$ x 10 ppm = $6x10^{-15}$
• f_{sc} (SM2) = $1x10^{-9}$ x 10 ppm = $1x10^{-15}$
• f_{sc} (SM3) = $4x10^{-9}$ x 10 ppm = $4x10^{-15}$

Small lens

- Beam is converging on this 2 inch lens (RoC = 100mm)

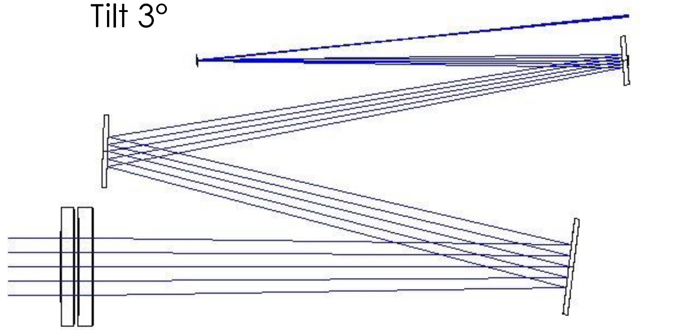
$$f_{sc}^{first} \cong \left| \langle \phi(x,y) | \phi_0(x,y) \rangle \right|^2 \times R_{AR} = 9 \cdot 10^{-5} \times 10^{-4} = 9 \cdot 10^{-9}$$

$$f_{sc}^{second} \cong \left| \langle \phi(x,y) | \phi_0(x,y) \rangle \right|^2 \times R_{AR} = 5 \cdot 10^{-4} \times 10^{-4} = 5 \cdot 10^{-8}$$

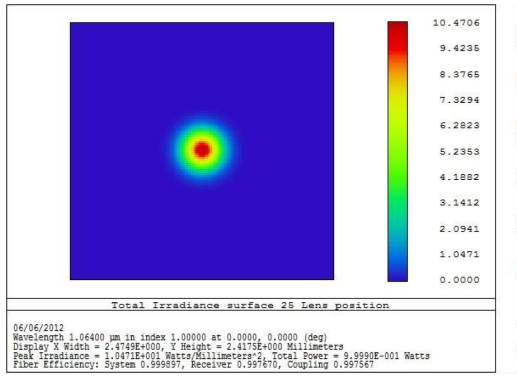
- If the diffusion of the lens is too big (see after) –> not possible to tilt the lens (> 3.5° in order to separate the beams → coupling less than 76%)

- Another solution, add a spherical mirror and then tilt the lens

Spherical mirror
Tilt 3°



Bi-convex lens
RoC = 1m – Tilt 10°



Coupling
efficiency = 0.997

Fraction of diffused light: summary for end benches

- Fraction of backscattered light (for 1 W ITF output)

- f_{sc} (total for 3 steering mirrors) ~ 10^{-14} (TIS=10 ppm)
- f_{sc} (doublet total for 4 faces)~ 5×10^{-10} (R_{AR}=0.5%)
- f_{sc} (small lens) = 5×10^{-8} (if not tilted, if tilted this contribution is negligible)

- Remark:
  - this is the light directly recoupled with the main beam (not secondary scattering from baffles, tubes)

$$h = \sqrt{f_{sc}} T \frac{\lambda}{4\pi} \frac{1}{L} \sin(\varphi) = \sqrt{5 \cdot 10^{-8}} \times 2.5 \cdot 10^{-17} \sin(\varphi) = 6 \cdot 10^{-21} \sin(\varphi)$$

- Re-measurement of doublet at LMA should allow to check these numbers

Noise projections

Work in progess…

Summary

• Re-computation on coupling factors for different telescopes (with some differences with respect to previous notes and TDR)

• Computation of backscattering of light directly recoupled with main beam (not secondary scattering)

• Computation for detection and end benches. Some computation, with minor changes, is also valid for injection and pick-off telescope

• Matlab code for computation of diffusion (ADOC)

• Model proposed for the role of defects and AR coating for lenses → the important factor is the AR coating, not the RMS

• Discussion with LMA to perform measurements to check the AR coating role

• Proposed strategy to avoid up-conversion in case of bad weather, using coherence between local controls (without new hardware on the benches)

• Projections of noise for detection bench done – projection for end benches on going