Back-scattering / Back-reflection / Astigmatism / Spherical aberrations

Comparisons and Conclusions for Telescopes

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Definitions

- Fraction of the incident beam back-scattered by the mirrors (photodiodes, beam dumps) and recombine with the main beam:

$$f_{sc} = \frac{P_{sc}}{P_{in}} = BRDF\,\frac{\lambda^2}{\pi\omega_0^2}$$

- For lenses, the back-reflection dominates:

$$f_{sc} = R_{AR} C_{00}$$

- Field back-scattered or back-reflected:

$$h_{sc} = K\sqrt{f_{sc}} \times \sin\phi_{sc}$$

Lenses

- Back-scattered light (VIR-642A-08 – Benjamin Canuel)

Lenses	Integrated scattering	fsc	$K_{det}\sqrt{f_{sc}}$
Optosigma – Plano Convex f=200 mm	80-200 ppm		
Optosigma – Plano Convex f=300 mm	25-60 ppm		
CVI Bi Convex f=200 mm	15-40 ppm		
CVI Bi Convex f=500 mm	30-40 ppm		
SDB_L1 Plano Convex f=2059.5 mm	11 ppm	7 x 10^{-10}	2.6 x 10^{-19}

Before OMC

$K_{end} = 1\times10^{-14}$

By considering that

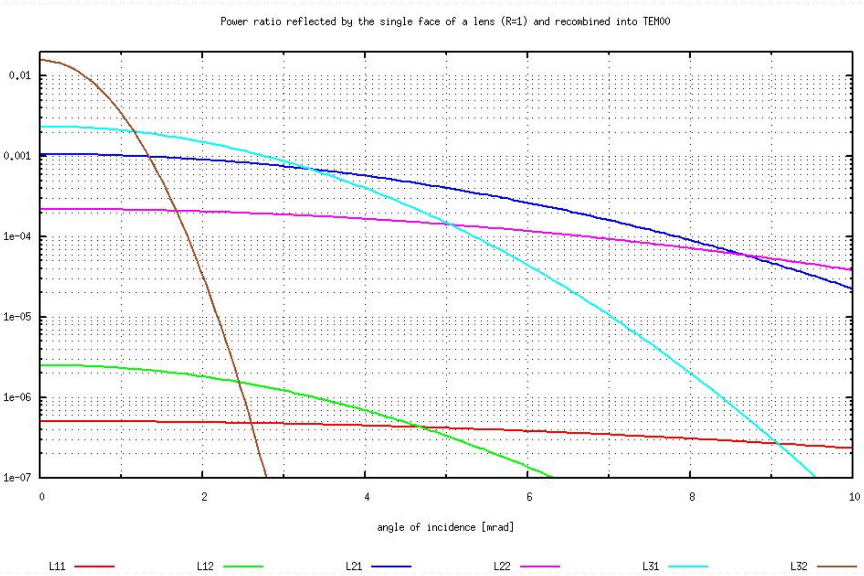
$\omega_0 = 30\mu m$

Weak Scattering (BRDF) – But really negligible than back-reflection?

Lenses

- Back-reflected light (VIR-369A-08 – Julien Marque / VIR-NOT-070A-08 – Edwige Tournefier)

Lenses	C_{00}	fsc	$K_{det}\sqrt{f_{sc}}$
SDB_L1 – Plano Convex f=2059.5 mm	1 ppm	10^{-9}	3×10^{-19}
SDB_L3 – Plano Convex f=448.7 mm	10 000 ppm	10^{-5}	3×10^{-17}



Tilt lenses should decrease the back-reflected which couples with the main beam
Experimentally, no effect

Back reflected light not really play a role

Lenses

- Back-reflected light (Extrapolation to the end benches)

Lenses	C_{oo}	fsc	$K_{end}\sqrt{f_{sc}}$
SDB_L1 – Plano Convex f=2059.5 mm	1 ppm	10^{-9}	$1.9 x 10^{-22}$
SDB_L3 – Plano Convex f=448.7 mm	10 000 ppm	10^{-5}	$1.9 x 10^{-20}$

Lenses

- Surface quality (typically for detection lenses and end benches lenses)
  - Surface flatness: λ/10
  - Surface quality: 20-10
  - Surface roughness: 10 Å rms
  - AR coating: 10^{-3}

Spherical mirrors

- Back-scattered light (VIR-642A-08 – Benjamin Canuel)

Mirrors	Integrated scattering	fsc	$K_{det}\sqrt{f_{sc}}$	$K_{end}\sqrt{f_{sc}}$
CVI substrate (fused silica) coated by LMA	60-100 ppm	3.8 x 10^{-9}	6.2x 10^{-19}	3.7x 10^{-22}
General Optics super polished coated by LMA	15-45 ppm	9.5x 10^{-10}	3 x 10^{-19}	1.8x 10^{-22}

By considering that

$$\omega_0 = 30\mu m$$

$$K_{end} = 0.6\times10^{-17}$$

→ Comparable to the lenses

Spherical mirrors

- Surface quality (typically for CVI mirrors)
  - Surface flatness: λ/10
  - Surface quality: 10-5
  - Surface roughness: ~ 1 Å rms ? To be confirmed

⇒ Good surface quality

Parabolic mirrors

- Back-scattered light (Substrate-Optical Surface / Coating - LMA)

Mirrors	Integrated scattering	fsc	$K_{inj}\sqrt{f_{sc}}$	$K_{\det}\sqrt{f_{sc}}$	$K_{end}\sqrt{f_{sc}}$
SIB_M5 f=74.48 mm	89 ppm	5.6 x 10^{-9}	2.5x 10^{-24}	7.5x 10^{-19}	4.5x 10^{-22}
SIB_M6 f=604 mm	323 ppm	2x 10^{-8}	4.8 x 10^{-24}	1.4x 10^{-18}	8.6x 10^{-22}

$K_{inj} = 3.3\times10^{-20}$

By considering that

$\omega_0 = 30\mu m$

Parabolic mirrors

- Surface quality (Substrate-Optical Surface / Coating - LMA)
  - Surface flatness: λ/10 (SIB_M5) and λ/9 (SIB_M6)
  - Surface quality: 40-20 (SIB_M5) and 20-10 (SIB_M6)
  - Surface roughness: 9 Å rms (SIB_M5) and 15 Å rms (SIB_M_6)

→ Surface quality less good than spherical mirrors, but back-scattering comparable

Parabolic mirrors

- Comparison with parabolic mirrors on LIGO end benches

  - Surface flatness: λ/10 (SIB_M5) and λ/9 (SIB_M6) - **λ/4 (PPM) and λ/4 (SPM)**
  - Surface quality: 40-20 (SIB_M5) and 20-10 (SIB_M6) – **60-40 (PPM) and 60-40 (SPM)**
  - Surface roughness: 9 Å rms (SIB_M5) and 15 Å rms (SIB_M$_6$) - **< 100 Å rms (PPM) and < 100 Å rms (SPM)**

⇒ Surface quality less good than VIRGO parabolic mirrors

Spherical aberrations

- Lenses and Spherical mirrors induce spherical aberrations. Actually, on the end benches, the doublet limit these aberrations and the Seidel term is 2.10^{-5}.

- Spherical mirrors could induce astigmatism, which may be necessary for the MMT on the injection bench, but not for detection benches.

Confrontation of the results

	BRDF ou C_{oo}	f_{sc}
SDB_L1 – Plano Convex f=2059.5 mm	1 ppm	10^{-9}
SDB_L3 – Plano Convex f=448.7 mm	10 000 ppm	10^{-5}
CVI substrate (fused silica) coated by LMA	60-100 ppm	3.8×10^{-9}
General Optics super polished coated by LMA	15-45 ppm	9.5×10^{-10}
SIB_M5 f=74.48 mm	89 ppm	5.6×10^{-9}
SIB_M6 f=604 mm	323 ppm	2×10^{-8}

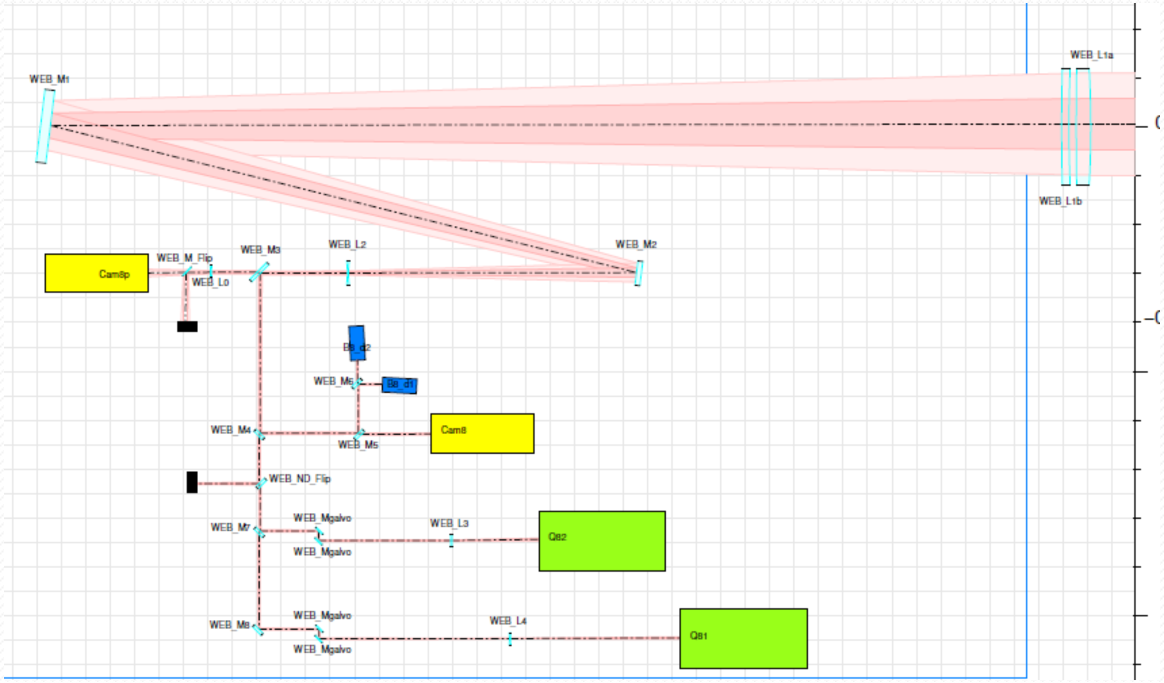
Constraints for AdV (VIR-NOT-070A-08):

- End benches: $f_{sc}<10^{-8}$
- SDB: $f_{sc}<4.10^{-7}$

Theory / Experimental constraints seem to say that parabolic mirrors are the best choice.

Summary

- End benches:
  - Replace lenses by parabolic mirrors?
  - Use lenses only for quadrant photodiodes waist size adaptation
  - Increase the waist size for the back scattering light



Summary

- Detection benches:
  - Replace lenses by parabolic mirrors?