Importance of cleanliness for ET

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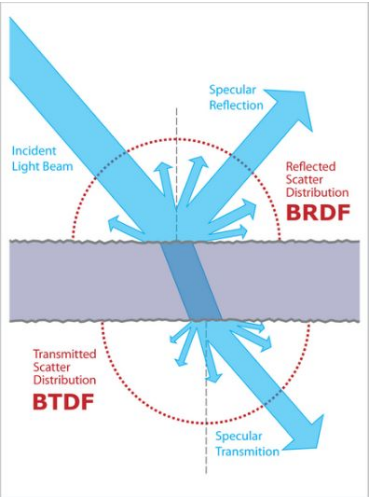
A short intro

Scattered light has many different origins:

- roughness of optical surfaces (mirrors, lenses, viewports,..)
- bulk of transmissive optical components (mirrors, polarizers, TGG,..)
- unstopped ghost beams (from residual reflectivity/transmissivity of AR/HR coatings)
- scattering/reflection off of baffles, dumpers, photodiodes,..
- particles deposited on optical surfaces or on light-receiving parts (baffles, dumpers, photodiodes,.)
- particles traversing the light beams
- ….



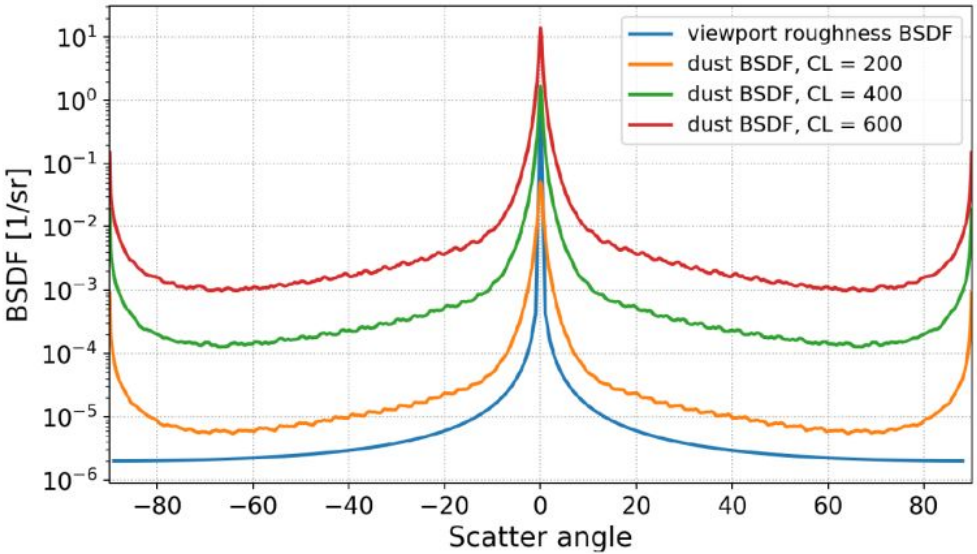
The Bidirectional Scattering Distribution Function (BSDF) is used to characterize scattering as a function of the angular position of the incident and scattered beams. [units of steradian^{-1}]

We focus here on the stray light due to particulates deposited on surfaces. Cleanliness regards the contamination levels in terms of particulates (number and size) allowed to deposit on surfaces.

Scattering : roughness vs particulate

Thanks to the high quality of the optics, the surface roughness may not be the dominant source of scatter , already in Virgo (at least in air)

The BSDF due to particles deposited on optics has a very similar angular dependence as the scattering from surface roughness



Viewport used in AdV O3 for FIS:
0.3nm surface roughness (TIS = 12ppm)

CL=200 (i.e. 1 particle> 200um in 0.1m^2, for a steep particle distribution ie s=-0.927) corresponds to (in horizontal orientation):

- 11 years in ISO 3 (class 1)
  → e.g. Perugia clean room of AdV
- 600 days in ISO 4 (class 10)
- 100 days in ISO 5 (class 100)
- 20 days in ISO 6 (class 1000)
  → e.g. DET of AdV

Stray light: scaling with wavelength

- Scattering from surface roughness :
  - TIS prop to wavelength^{-2}
- Scattering from surface particulate contamination :
  - TIS little dependent on wavelength

→ in ET-LF scattering from particulate contamination expected to be relatively more important wrt scattering from surface roughness

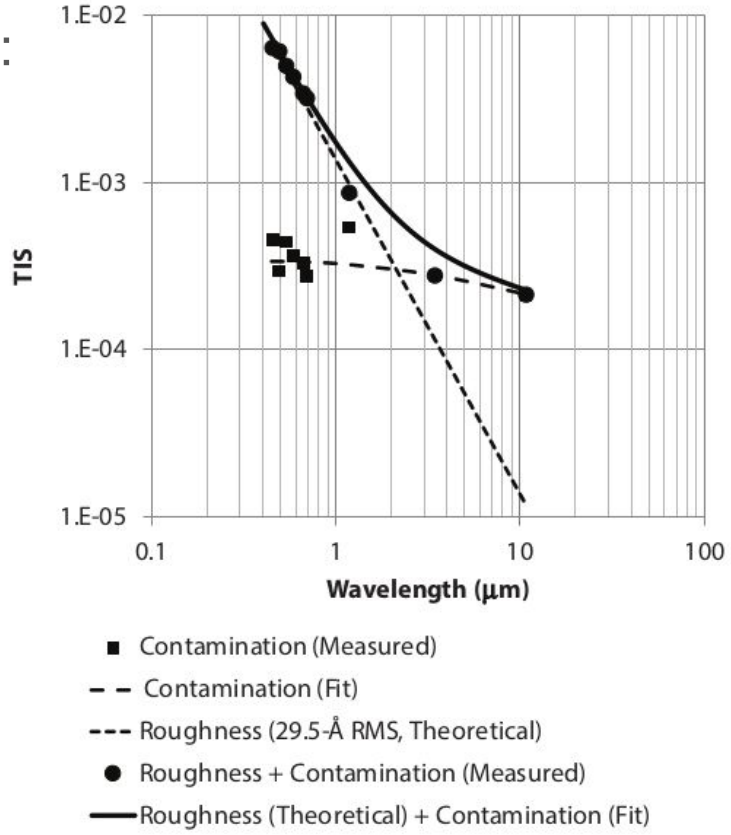


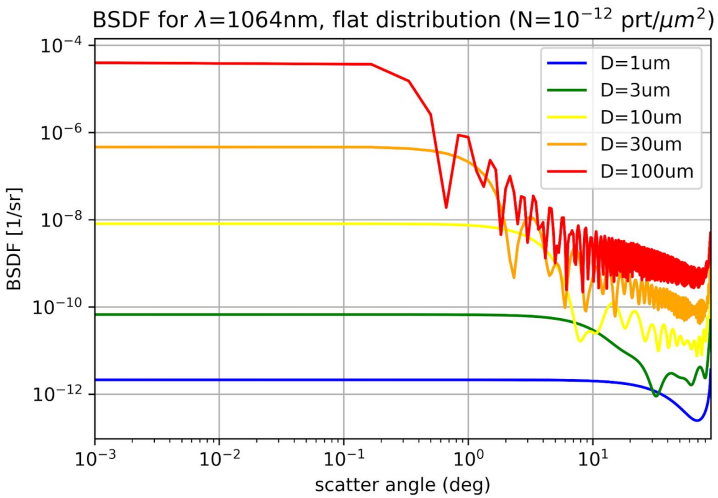
Figure 5.16 TIS versus wavelength of scattering from particulates and roughness.[25] TIS is measured at multiple points on a contaminated piece of polished flint glass with RMS roughness of 29.5 Å. Measured contamination TIS is estimated as the difference between the minimum TIS and the average TIS.

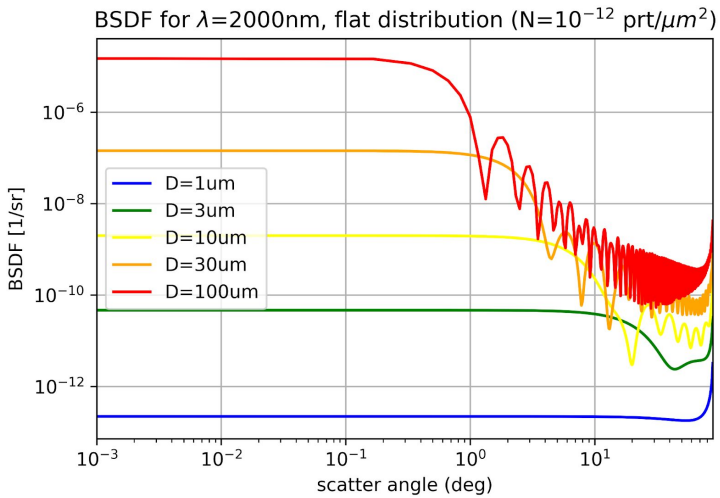
TIS = Total Integrated Scattering

Scattering from particulate deposited on optics

Large particles tend to scatter more and at smaller angles wrt small particles.

Assuming a flat distribution of particle numerosity vs diameter:

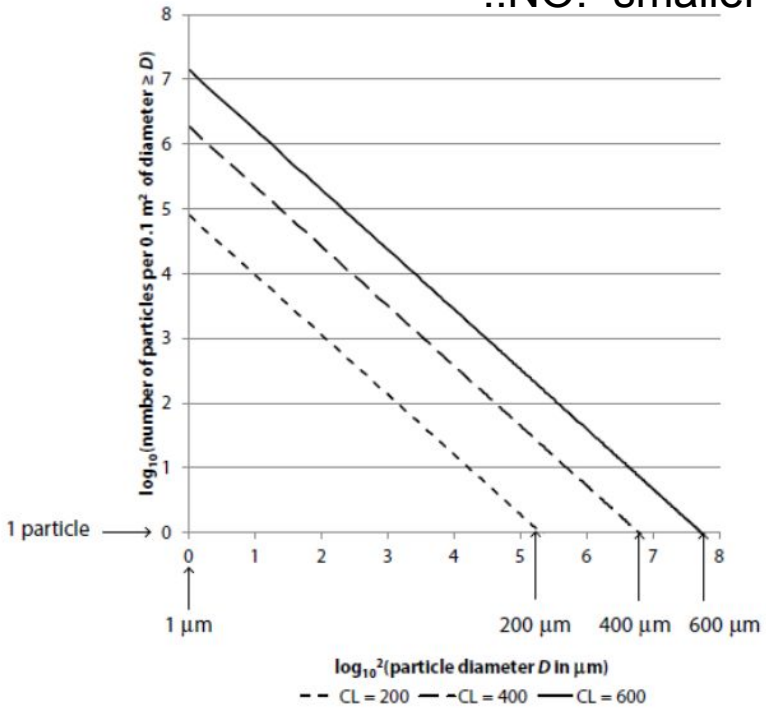


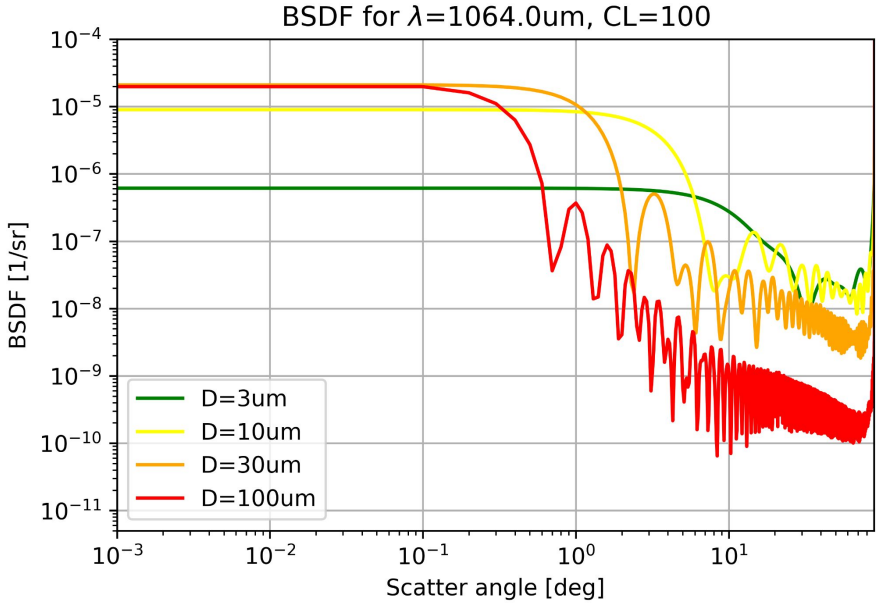


Can we neglect small particles? …

Scattering from particulate deposited on optics

..NO! smaller particles are typically more numerous

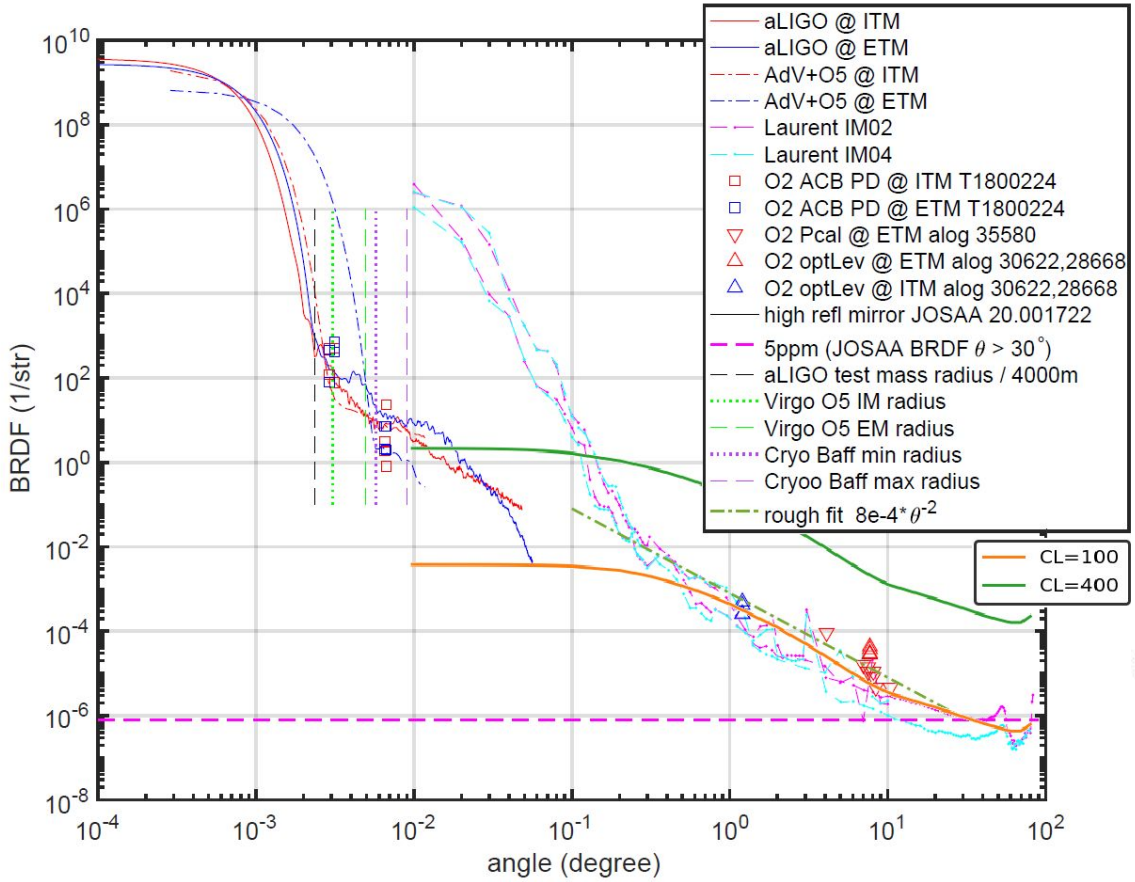




Summing up the contributions of small particles, this becomes relevant, especially at mid-large angles.

- size of particles giving largest contribution depends on the actual distribution of particle numerosity vs diameter & on the scattering angles of concern
- even with a steep distribution, particles about the size of the wavelength are less important

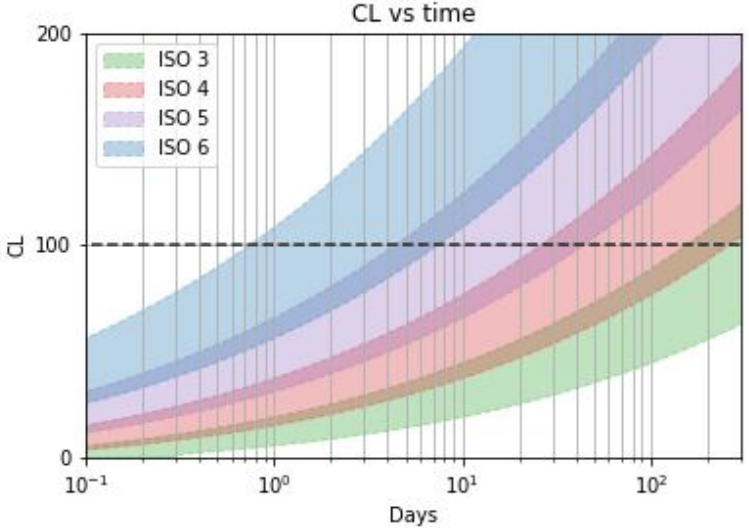
A comparison with the test-mass mirrors



Original plot from: A Romero-Rodríguez, Galaxies 10, (2022), 86

This comparison can help in setting requirements for cleanliness in ET towers

Assuming ideal, ISO conditions, bands for vertical/horizontal orientation:



Wish list for ET infrastructure:

- nested environments with progressive levels of cleanliness
- all important areas (towers, optical benches in air and in vacuum) under laminar flow when exposed
- clean spaces for assembly and cleaning of optics and equipment
- all clean areas dimensioned to guarantee target cleanliness level also during human activities (assembly, installation, commissioning, maintenance, cleaning)
- venting of vacuum volumes with clean air

- Clean rooms close to the installation places and/or clean transport procedures
- Availability of clean storage rooms
- Availability of tools/rooms for cleaning optics

What we can do better wrt Virgo

- define clear procedures to operate in clean environments (including usage of clean tools, etc...)
- define cleaning procedure for optics and other hardware:
  - before they are installed
  - after they are installed
  - do we need to consider cleaning of suspended optics/baffles ?

  eg by collecting procedures followed in different labs, also considering industry standards (semiconductor, pharmacy)

- Make sure people are trained
- Systematic dust monitoring system, to alert of bad procedures or when cleaning intervention is required

(lots already done in LIGO, KAGRA as a reference for underground operation)

Final recommendations

It should be clear that particle contamination can be a leading source of scattering in ET if not well addressed since the beginning

Plans for civil infrastructure should take cleanliness into account

Procedures for clean operations should be defined

ET members should receive adequate training