# Virgo Laser & related optics

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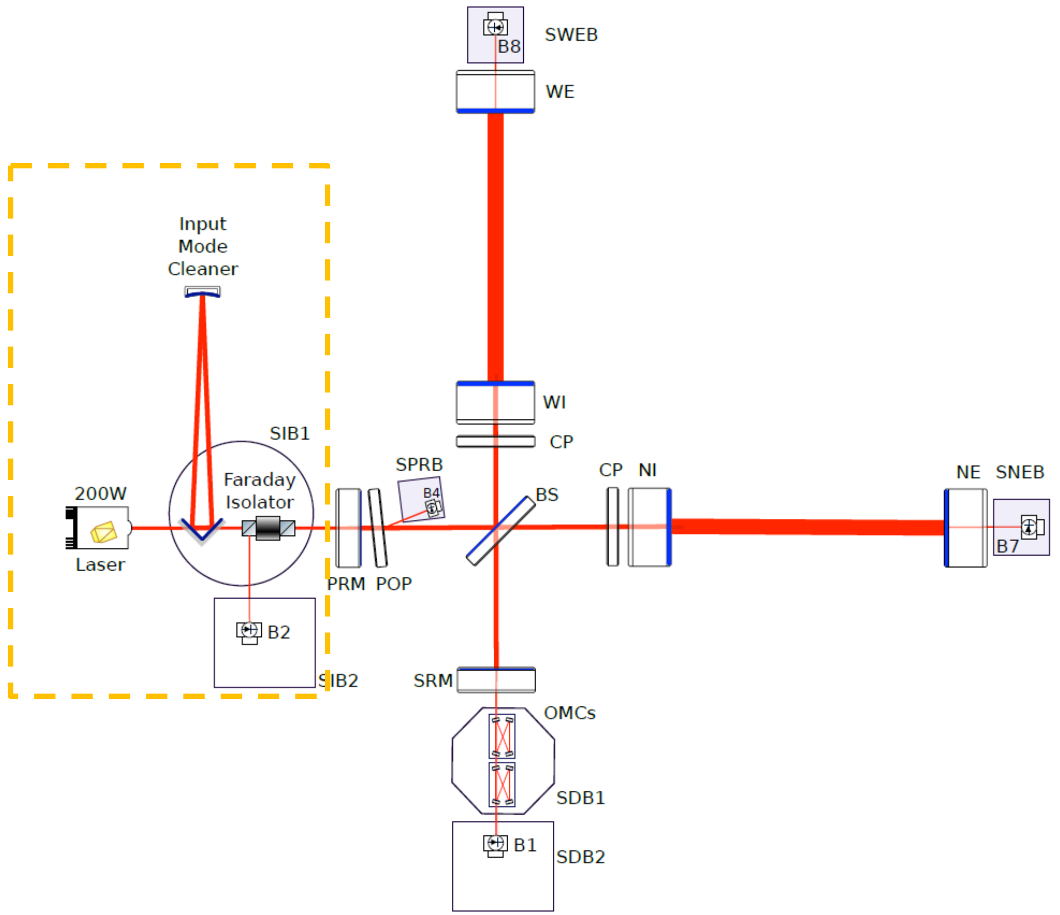
# Outline

- The Laser system
- The injection system
- Stray light control




*AdV optical layout*

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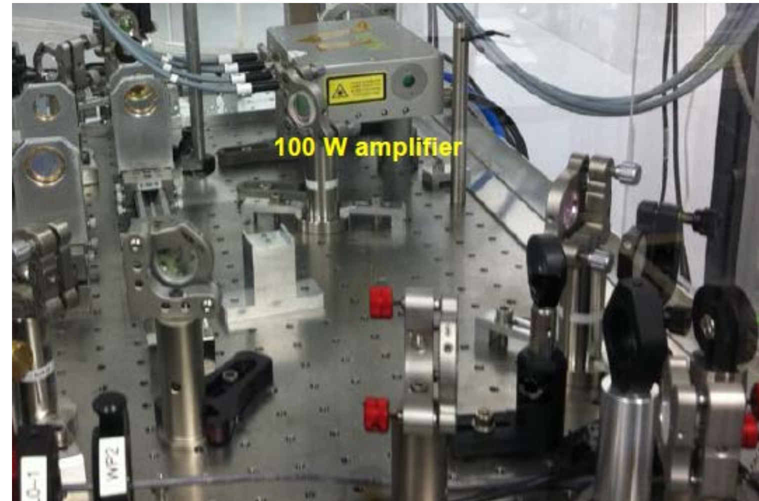
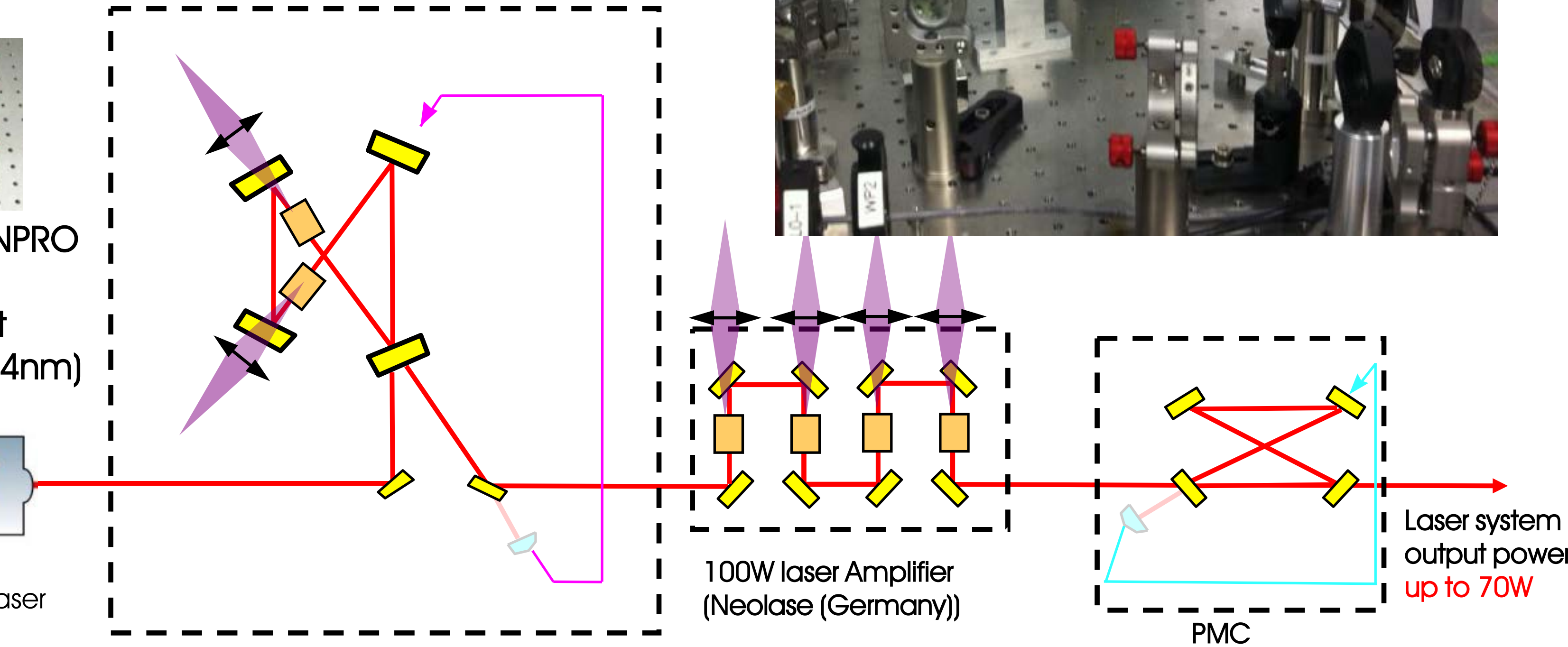
# *The Virgo/AdV (first phase) laser system*

20 W Nd:YVO4 slave laser
(Laser Zentrum Hannover)
*(injection-locked)*

Commercial NPRO
Nd:YAG Laser
from coherent
(P=1 W @1064nm)




Nd-YVO4 crystal

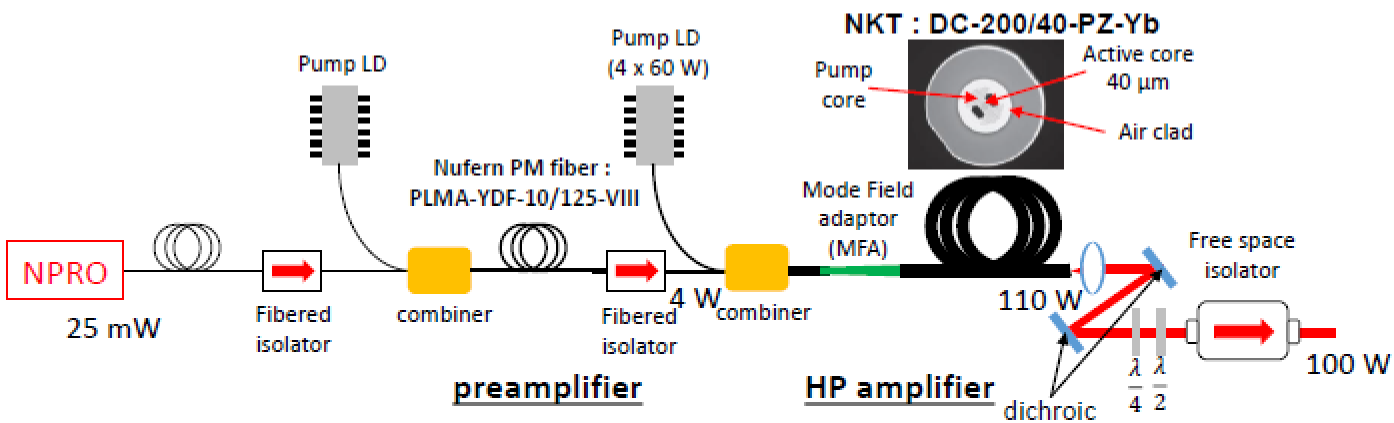
Crystal pumping module

*Collaboration between Artemis and EGO on that system*

# What next on the laser source?

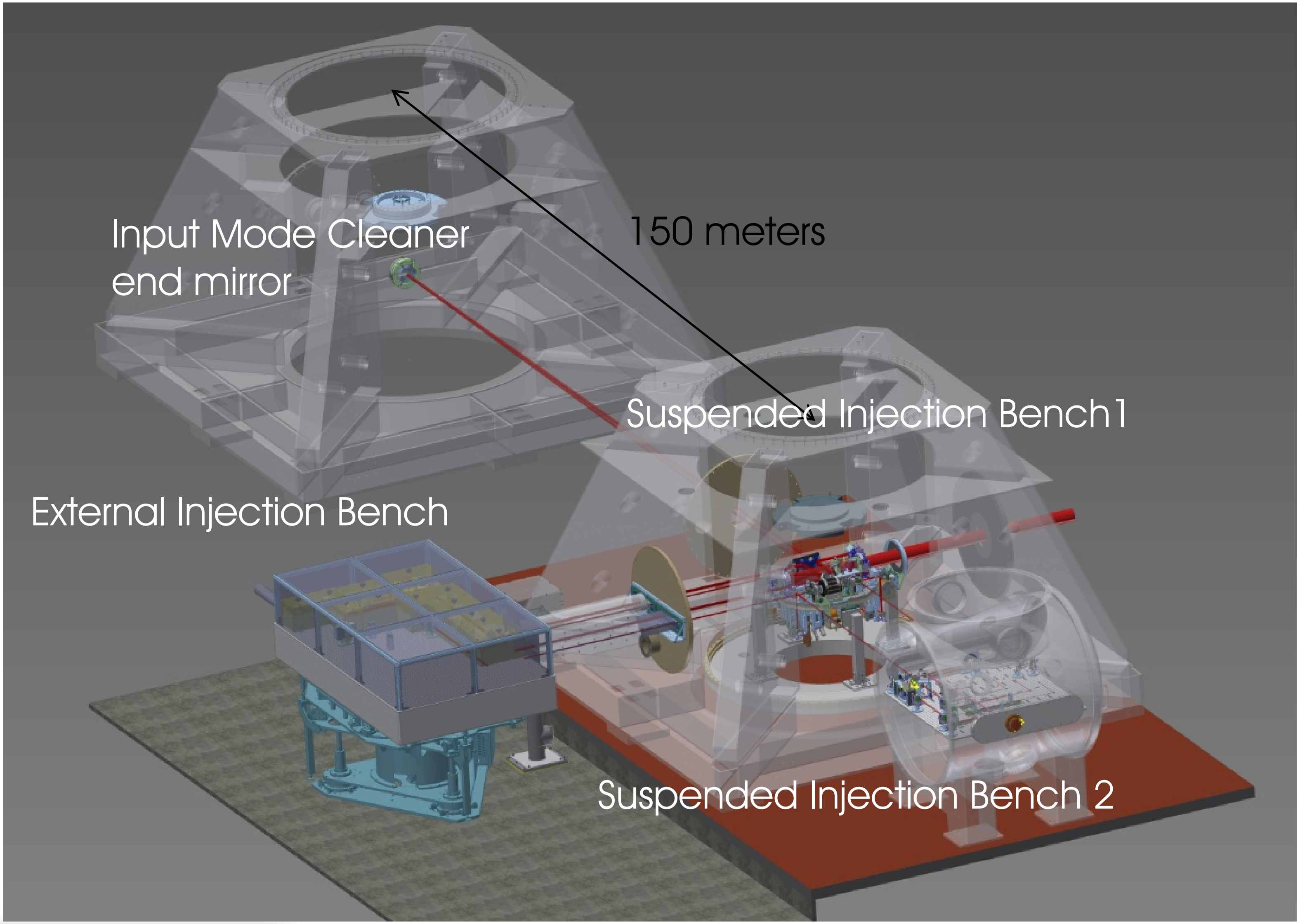
- Principle: sum coherently several laser amplifier modules up to get the required laser output power (200 W).

- The choice of the most reliable technology - either a solid state laser amplifier (from Neolase) or a fiber laser amplifier (from ALS/Alphanov) - is still to be frozen



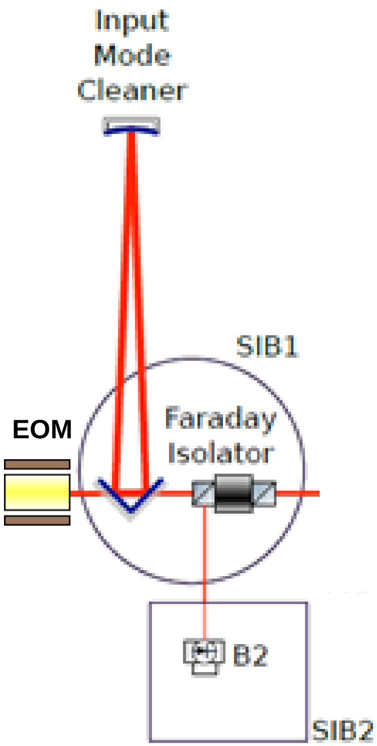

*Credits: W Chaibi (Artemis)*

# An overview of the AdV INJ subsystem



# The injection system

The Injection system (INJ) of AdV takes care of the optics downstream of the high power laser, and of the interface of these optics with the laser and the Interferometer.



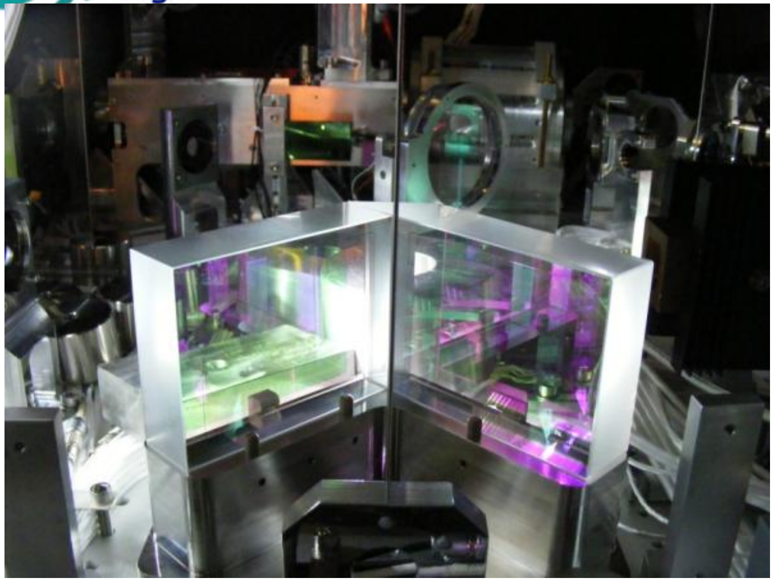

Main components:

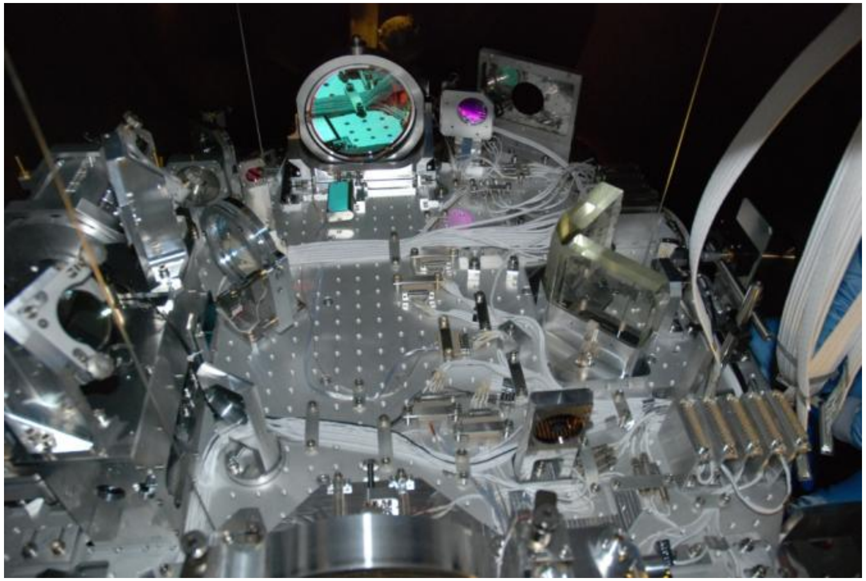
- Electro optic modulation system (EOM): Phase modulation of the laser beam to control the optical cavities and the interferometer.
- Input Mode Cleaner cavity: passively filter out amplitude, frequency and beam jitter noise
- Faraday isolator: isolates the Laser from the back-reflected light of the interferometer.
- Mode matching optics: Adjust the beam dimension to properly match it on the interferometer to reduce as much as possible the light lost from the Laser bench to the ITF

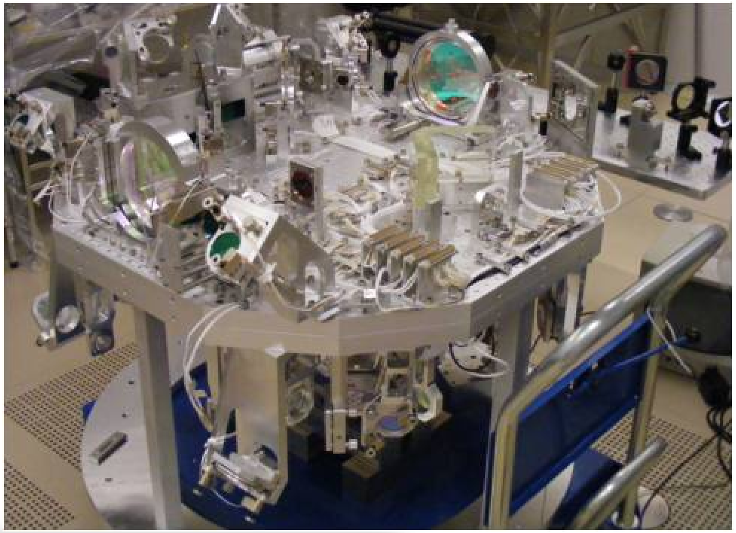
| Parameter | Requirement |
|---|---|
| Transmission to the ITF | $> 70\%\ TEM_{00}$ |
| Non-$TEM_{00}$ power | $< 5\%$ |
| Intensity noise | $2 \times 10^{-9}/\sqrt(Hz)$ at 10 Hz |
| Beam Jitter | $< 10^{-10}$ rad$/\sqrt(Hz)$ ($f$ >10 Hz) |
| Frequency noise (for lock acquisition) | <1 Hz r.m.s |

*Requirements from the Technical report*

# Complex optical systems design and realization







→ Ultra high vacuum compatible optical table used to inject the Laser beam in the Virgo Interferometer.
Used also to pre-stabilize the laser frequency (a rigid cavity is hanged to this table)

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# Development of high power compatible electro-optic modulators

- Requirements:
  - Withstand 200W CW laser power @1064nm.
  - Limited thermal lensing effect (low absorption crystal used (RTP)).
  - Maximum modulation depth = 0.2 rad. (mostly related to the RF oscillator).
  - Low Residual Amplitude modulation (RAM) noise.

Applications:
- Optical cavities locking (heterodyne detection)
- Frequency- modulation spectroscopy (low RAM required)
- Telecommunications?

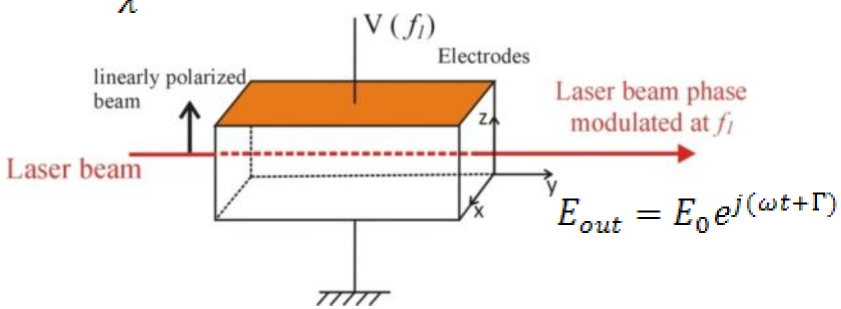
- Reminder:

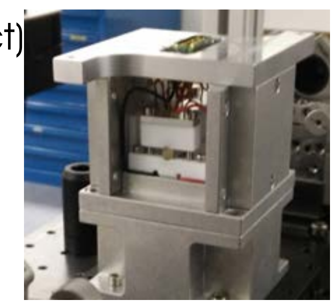
Phase shift induced by the electric field (Pockels effect)

$$\Gamma = \frac{2\pi}{\lambda} n_z L = \frac{2\pi}{\lambda} L(n_e - 0.5 n_e^3 r_{33} E_z) \qquad E_z = V/d$$

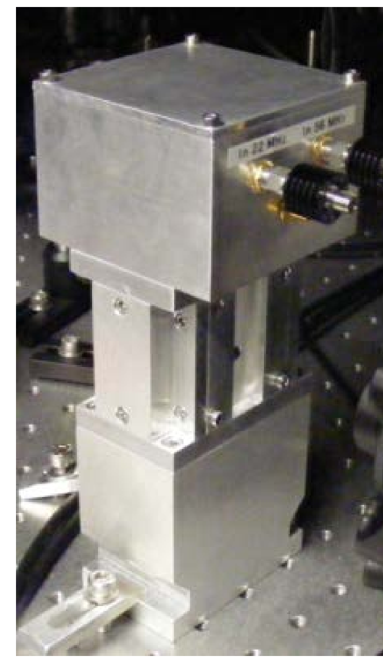
Modulation depth

$$\mathrm{m} = \frac{\pi}{\lambda} L(n_e^3 r_{33}) V_z/\mathrm{d}$$



Electro optic material chosen:
Rubidium Titanyle Phosphate – RbTiOPO4



2-frequencies EOM

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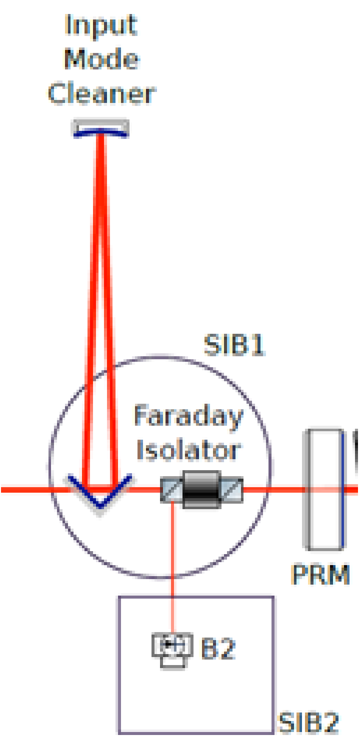
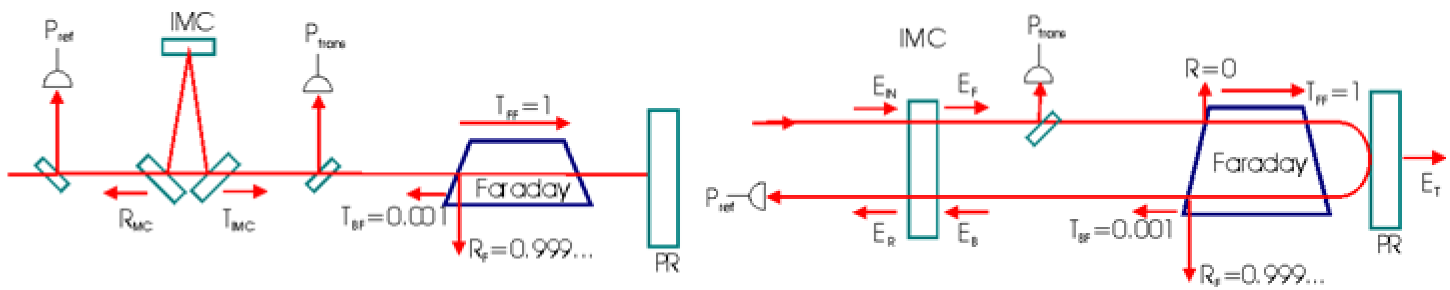
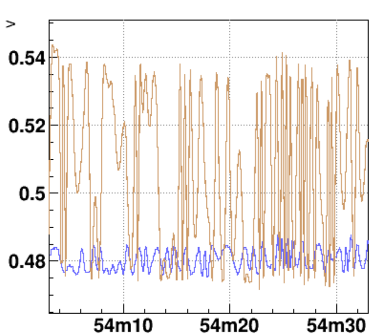
# *Development of high power vacuum compatible Faraday isolator*




- Function:
  - avoid to create a spurious cavity Input Mode Cleaner/ Interferometer. Due to the fact that IMC cavity is long (144m), we have a small angle of incidence on 1 mirror of the cavity and the back-scattered light from this optics can easily be recoupled in the IMC cavity



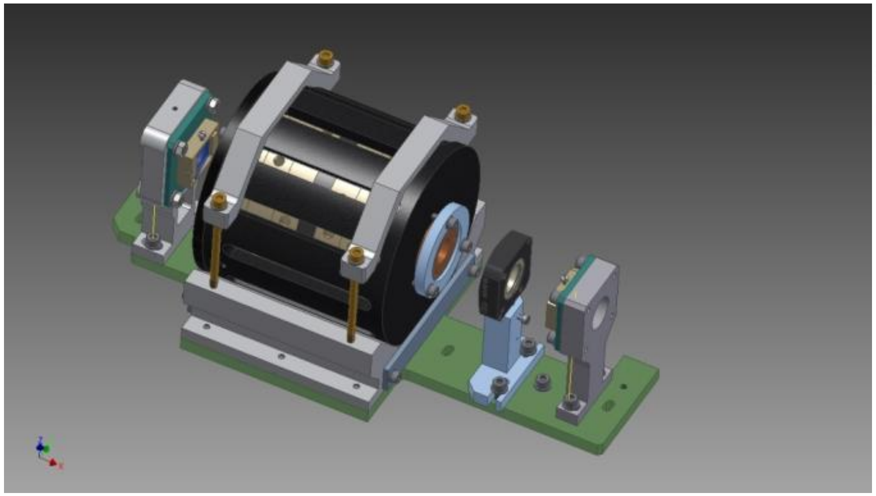

  - have an easy way to get the interferometer reflection (to be used for the interferometer control).
  - avoid to re-inject light in the laser system and damage it.

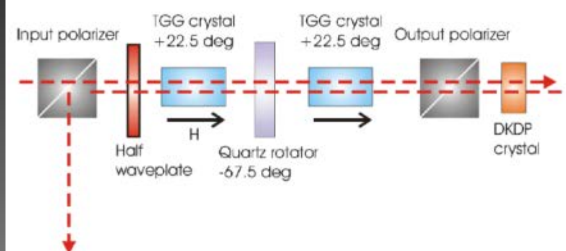


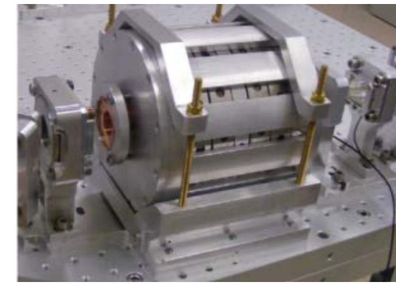

**In order to reduce these effects, we have to install a Faraday isolator between the IMC and the interferometer.**

# Development of high power vacuum compatible Faraday isolator

- A vacuum compatible Faraday isolator has been developed in collaboration with the Institute of Applied Physics (Russia) and the University of Florida (LIGO project)

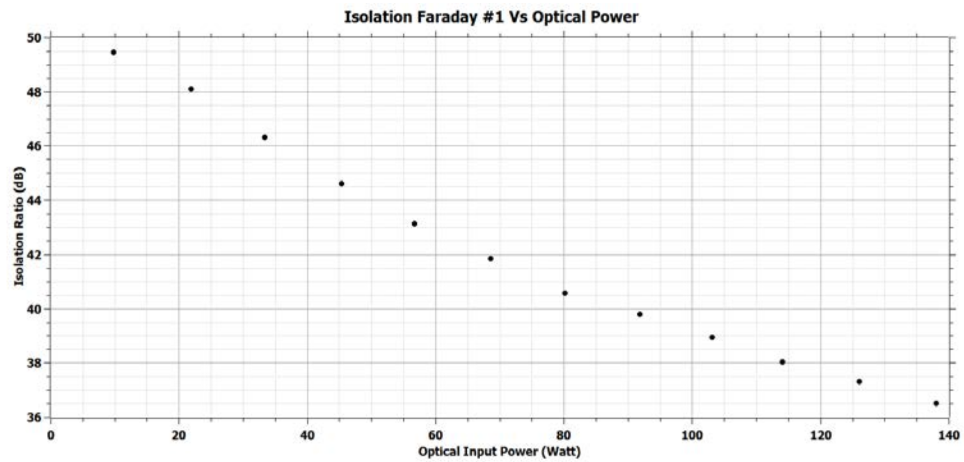




| Parameter | Requirement |
| --- | --- |
| Isolation(low to 150 W) | $\geq$ 40 dB |
| Total throughput | $\geq$ 95% |
| Residual thermal lens | > 100 m or <0.01 diopters at 150 W |
| Clear aperture | $\geq$ 20 mm |
| Vacuum compatibility | < $10^{-6}$ mBar |

*UHV Faraday isolator requirements*

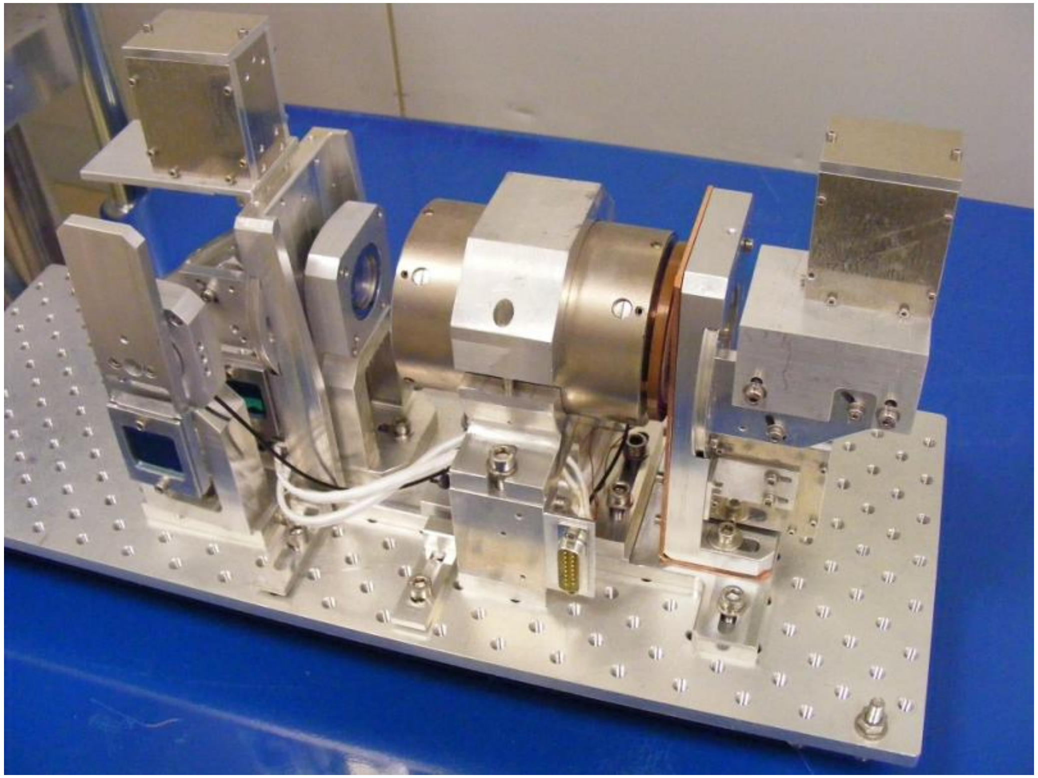



*Isolation ratio vs laser input power*

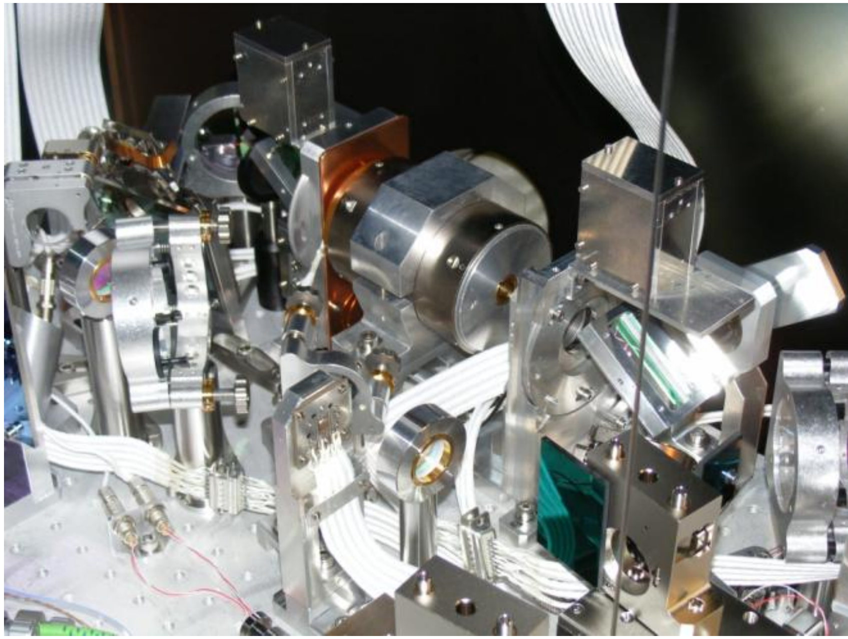
References:
[1] O. Palashov, D. Zheleznov, A. Voitovich, V. Zelenogorsky, E. Kamenetsky, E. Khazanov, R. Martin, K. Dooley, L. Williams, A. Lucianetti, V. Quetschke, G. Mueller, D. Reitze, D. Tanner, E. Genin, B. Canuel, and J. Marque, High-vacuum compatible high-power Faraday isolators for gravitational-wave interferometers, JOSA B, Vol. 29, Issue 7, pp. 1784-1792 (2012).

# *Vacuum compatible low-losses Faraday isolator for squeezed light injection*

| Parameter | Value |
|---|---|
| Isolation ratio | > 40 dB |
| Throughput | > 99.2% |



*Development of low losses Faraday isolator (losses<1%)*

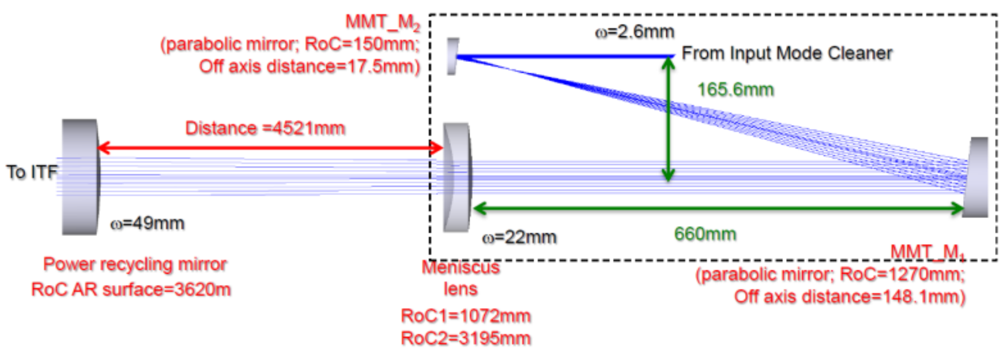


*The low losses Faraday isolator installed on the detection bench*

→ improvements are possible for the AdV upgrade. Reasonable to think to reach **more than 99.5% throughput** keeping a very good isolation ratio.

# High magnification beam expander/reducer

- Due to the large laser beam and the limited space available, we had to design an original and compact design for the launching telescope for Advanced Virgo. This is a catadioptric system.

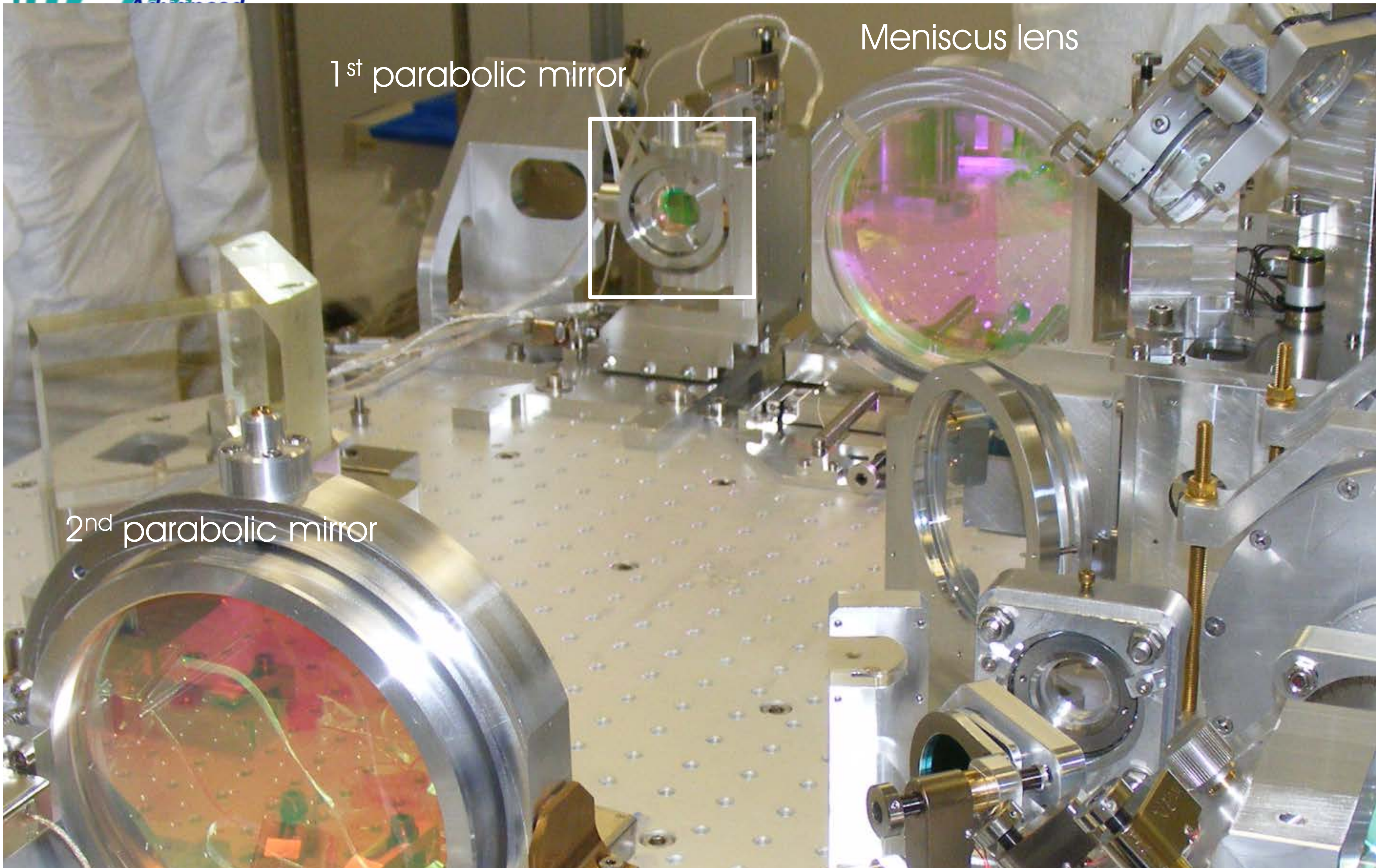



Applications:
- Astronomy (Laser guide stars)
- Whatever experiment which need a high magnification compact laser beam expander

→ This design has been chosen by the AdV Project for the interferometer input and output telescopes.

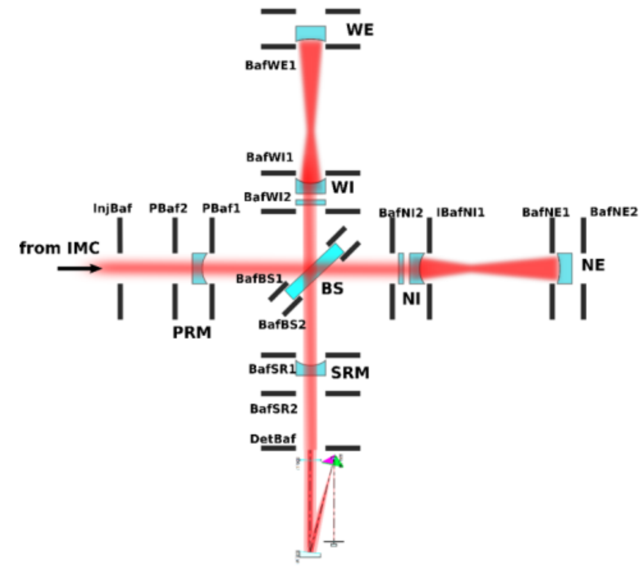

[1] C. Buy, E. Genin, M. Barsuglia, R. Gouaty, and M. Tacca, Design of a high-magnification and low-aberration compact catadioptric telescope for the Advanced Virgo gravitational-wave interferometric detector, *Class. Quantum Grav.*, 34 095011 (2017)
[2] M. Tacca, F. Sorrentino, C. Buy, M. Laporte, G. Pillant, E. Genin, P. La Penna, and M. Barsuglia, Tuning of a high magnification compact parabolic telescope for centimeter-scale laser beams, Applied Optics, Vol. 55, Issue 6, pp. 1275-1283 (2016).
[3] B. Canuel, E. Genin, G. Vajente, J. Marque, Displacement noise from back scattering and specular reflection of input and output optics in advanced GW detectors, Optics Express, Vol. 21, Issue 9, pp. 10546-10562 (2013).

# AdV launching telescope



# Stray-Light Control in Advanced Virgo

- ❑ A tiny amount of stray light coupling with the fundamental mode after "probing" the vibrations of infrastructures will bury any gravitational signal
- ❑ Baffles are put in place in order to catch light that deviates from intended path




- ❑ Selection of material driven by:
  - ❑ location-dependent requirements
  - ❑ validation of solution
  - ❑ trade-off with budget constraints

- ❑ Some materials used:

Cost increase ↑

| Material | LIDT | TIS |
|---|---|---|
| SiC + AR | 30kW/cm2 | ~20-50ppm |
| DLC + AR | 500W/cm2 | ~500-1000ppm |
| AR-on-steel | >50W/cm2 | ~300-500ppm |
| Abs. Glass + AR | ~1W/cm2 | ~100ppm |

See report: VIR-0482A-14
https://tds.virgo-gw.eu/ql/?c=10539

AR-coated (R<0.5%) metallic baffle

Tested also DLC coating
On SS in collaboration with the
Univ of West Scotland

https://tds.virgo-gw.eu/ql/?c=11308

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Thank you for your attention!