EGO Contributions to Optics Systems in Virgo

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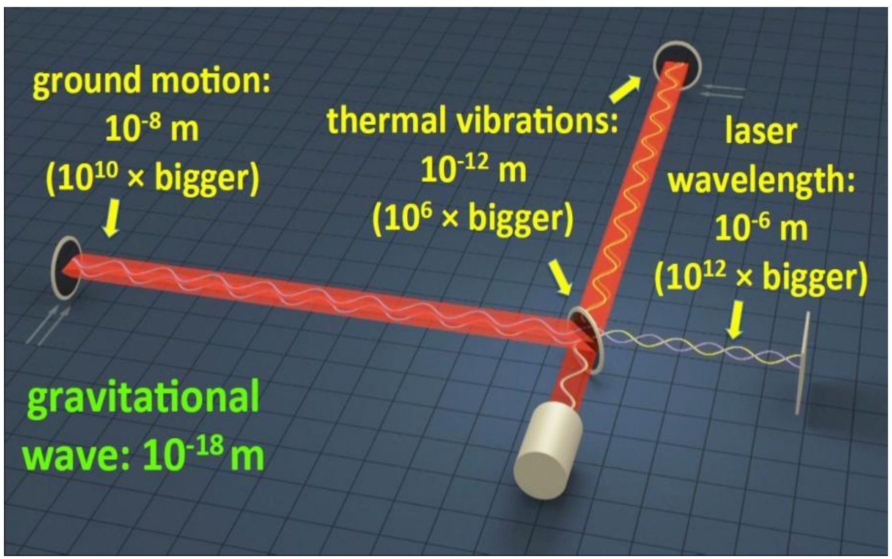
European Gravitational Observatory, Mar 21st, 2022

Virgo Interferometer & Noise

- Virgo is a null instrument: very sensitive to asymmetry and noises
- Technology is often stretched beyond the current limit to achieve the design sensitivity



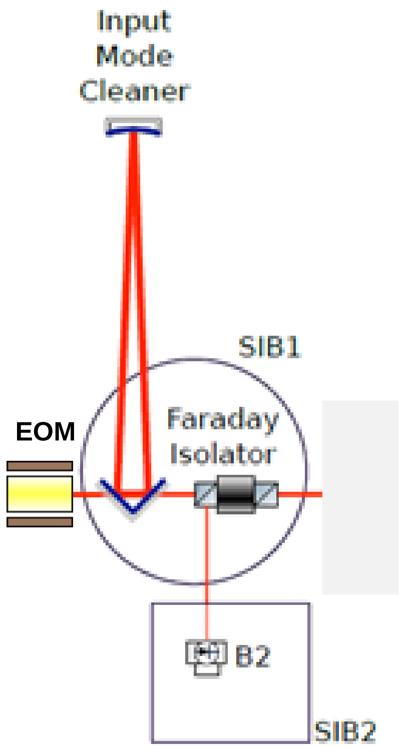
EGO Optics Group has been (and is!) involved in many of the optical system of the Virgo Interferometer:

- Laser Injection System
- Stray Light Control
- Auxiliary Laser System
- Thermal aberration Control System
- ...

Credits: Stephen Fairhurst

Overview of the AdV INJ subsystem

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:

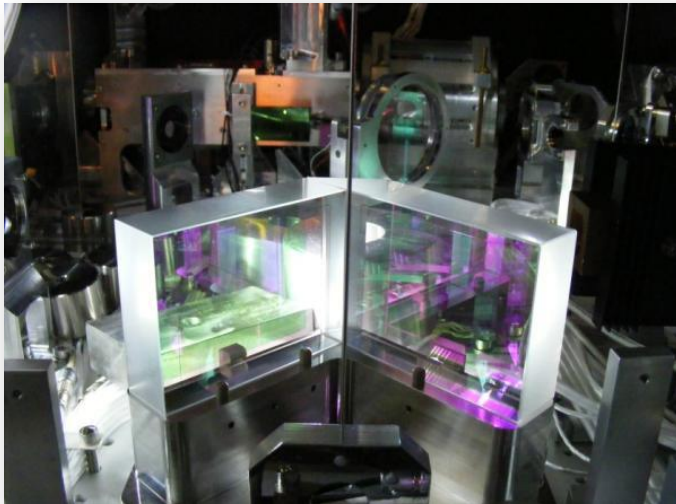
❑ Electro optic modulation system (EOM): Phase modulation of the laser beam to control the optical cavities and the interferometer.

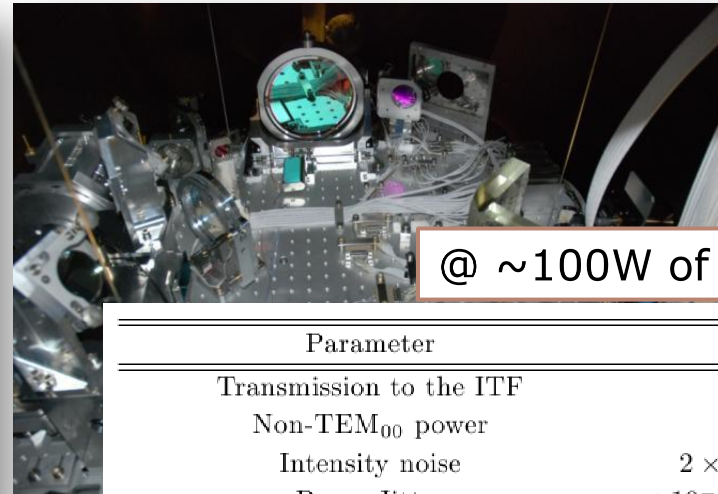
❑ Input Mode Cleaner cavity: passively filter out amplitude, frequency and beam jitter noise

❑ Faraday isolator: isolates the Laser and the IMC 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

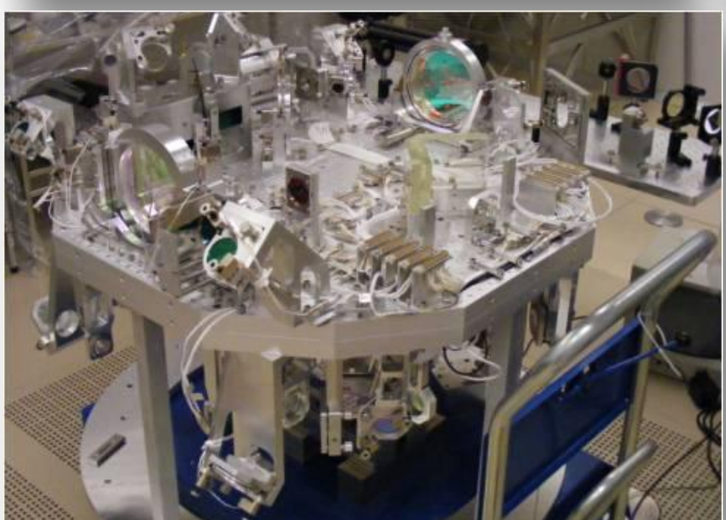
Complex optical systems design and realization





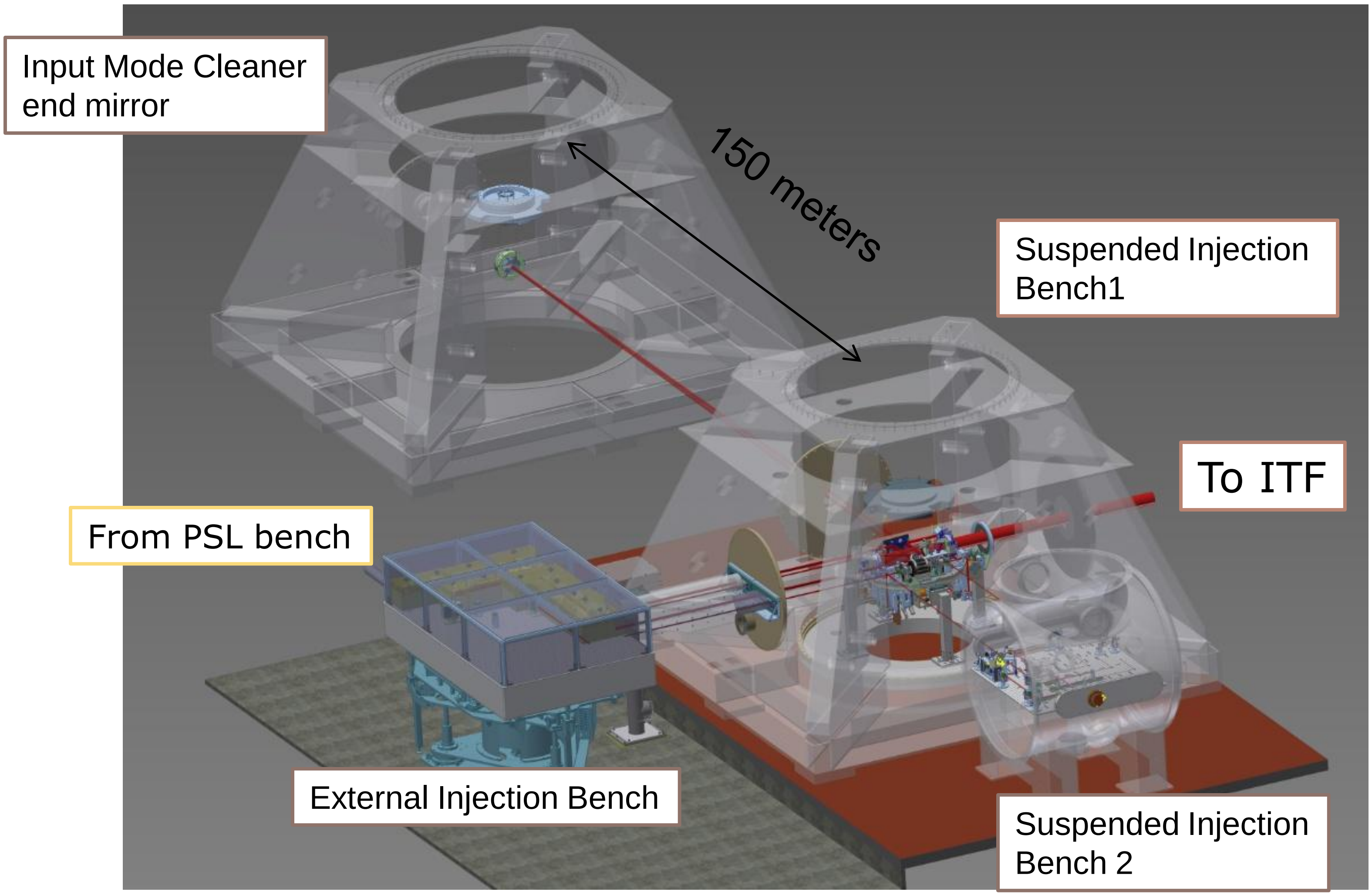
@ ~100W of delivered power

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



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

Overview of the AdV INJ subsystem



Complex optical systems design and realization

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IMC end mirror payload in MC tower

Development of custom components

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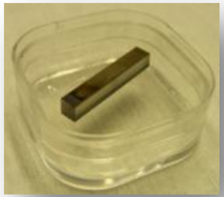
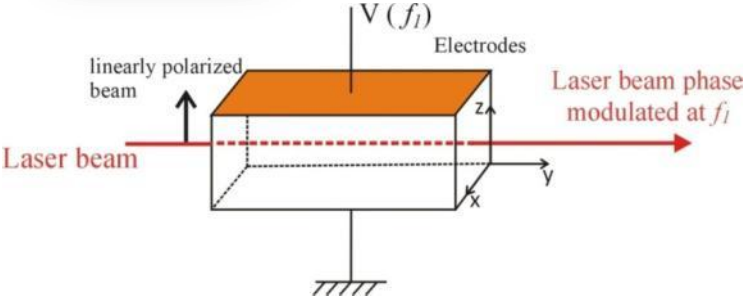
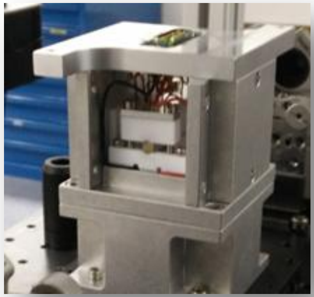
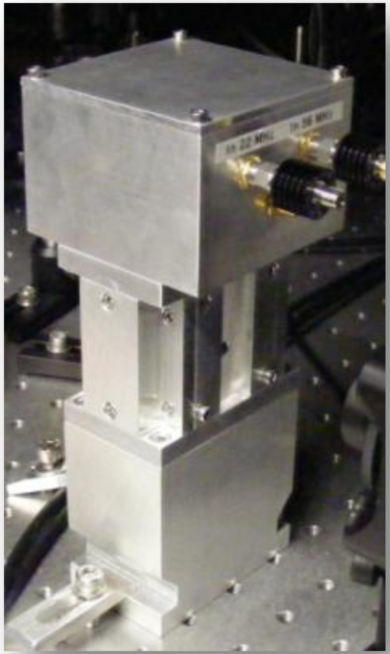
- high power compatible electro-optic modulators (EOM)
  - Requirements:
    - Withstand 200W CW laser power @1064nm.
    - Limited thermal lensing effect (low absorption crystal used (RTP)).
    - Maximum modulation depth = 0.2 rad.
    - Low phase noise (mostly related to the RF oscillator).
    -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



Electro optic material chosen:
Rubidium Titanyle Phosphate – RbTiOPO4







2-frequencies EOM

Development of custom components

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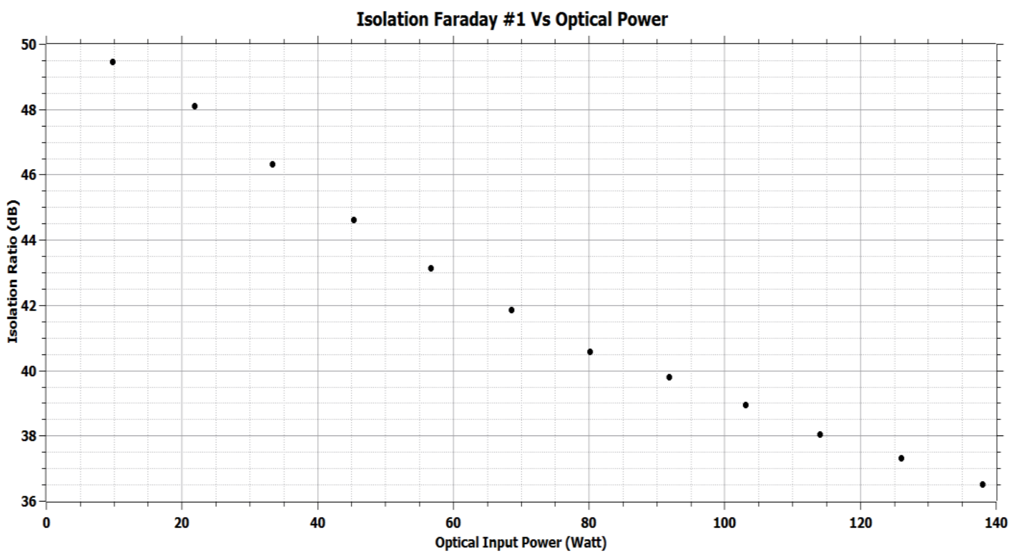
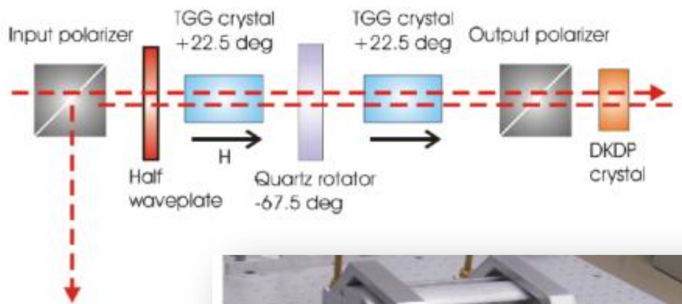
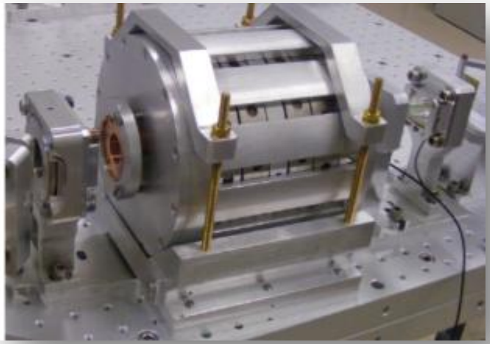
❑ high power, ultra-high vacuum compatible Faraday isolator (FI)

❑ FI developed in collaboration with the Institute of Applied Physics (Russia) and the University of Florida (LIGO project)







Reference:

[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).

Development of custom components

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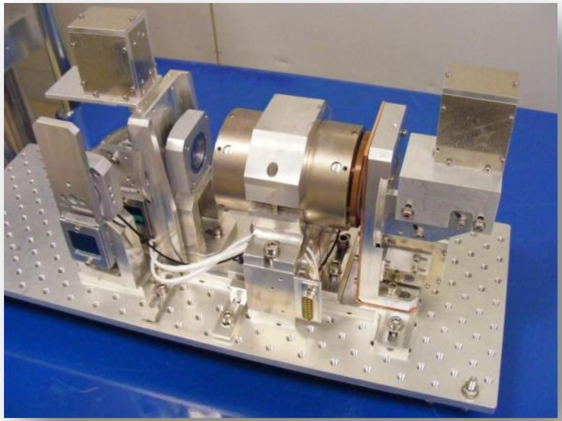
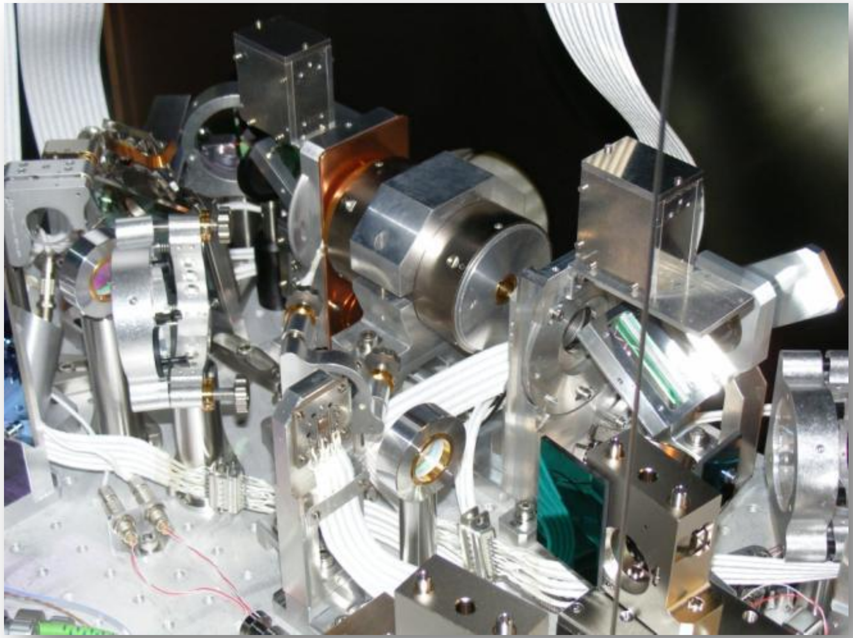
- low-losses, ultra-high vacuum compatible Faraday isolator (FI) for squeezed light injection

Parameter	Value
Isolation ratio	> 40 dB
Throughput	> 99.2%





The low losses Faraday isolator installed on the detection bench

Reference:
[1] Eric Genin, Maddalena Mantovani, Gabriel Pillant, Camilla De Rossi, Laurent Pinard, Christophe Michel, Matthieu Gosselin, and Julia Casanueva, "Vacuum-compatible low-loss Faraday isolator for efficient squeezed-light injection in laser-interferometer-based gravitational-wave detectors," Appl. Opt. 57, 9705-9713 (2018)

Stray-Light Control

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➢ Baffles are put in place in order to catch light that deviates from intended path

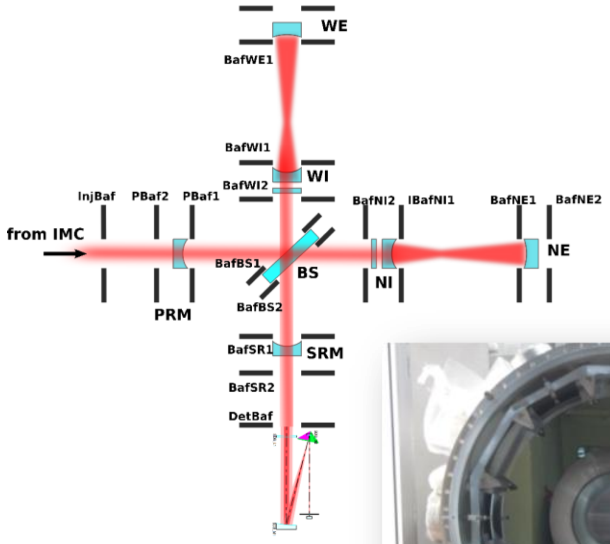
➢ Selection of material driven by:

- location-dependent requirements
- validation of solution
- trade-off with budget needs

❑ Some of the materials we used:

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

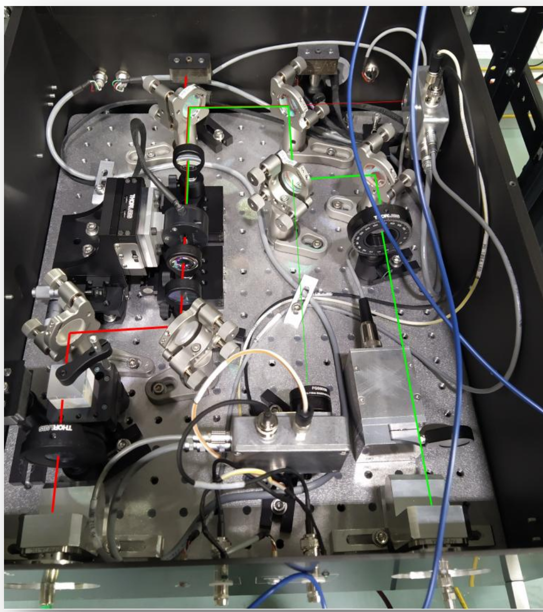
Cost increase

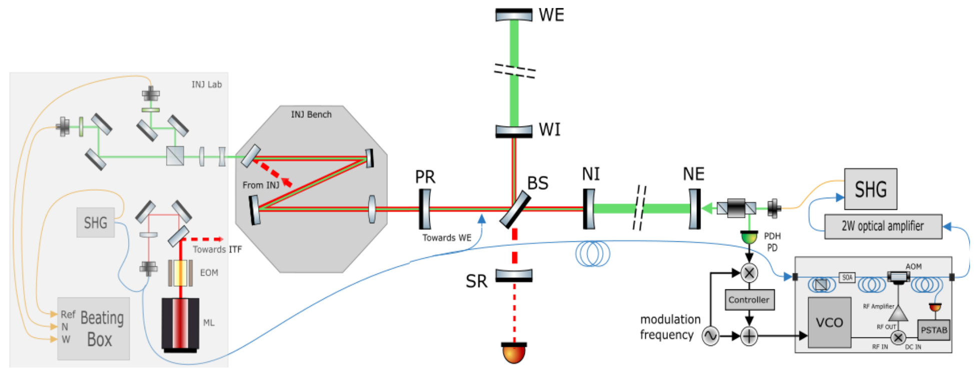


See report: VIR-0482A-14
https://tds.virgo-gw.eu/ql/?c=10539

Auxiliary Laser System

- Additional Mirror (Signal Recycling) installed
- Need for auxiliary laser to control the interferometer with the additional degree of freedom





- Enclosed in a box
- Inserted in a rack

- Chosen solution: no commercial green laser
- **Propagating a pick-off towards the end building with telecom optical fibers**
- **Amplifying and doubling it (SHG)**
- Locking the arms with green
- Beat-note with a reference in the central building to build the error signals and control the ITF

Thank you

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AdV INJ subsystem: simplified scheme with control loops

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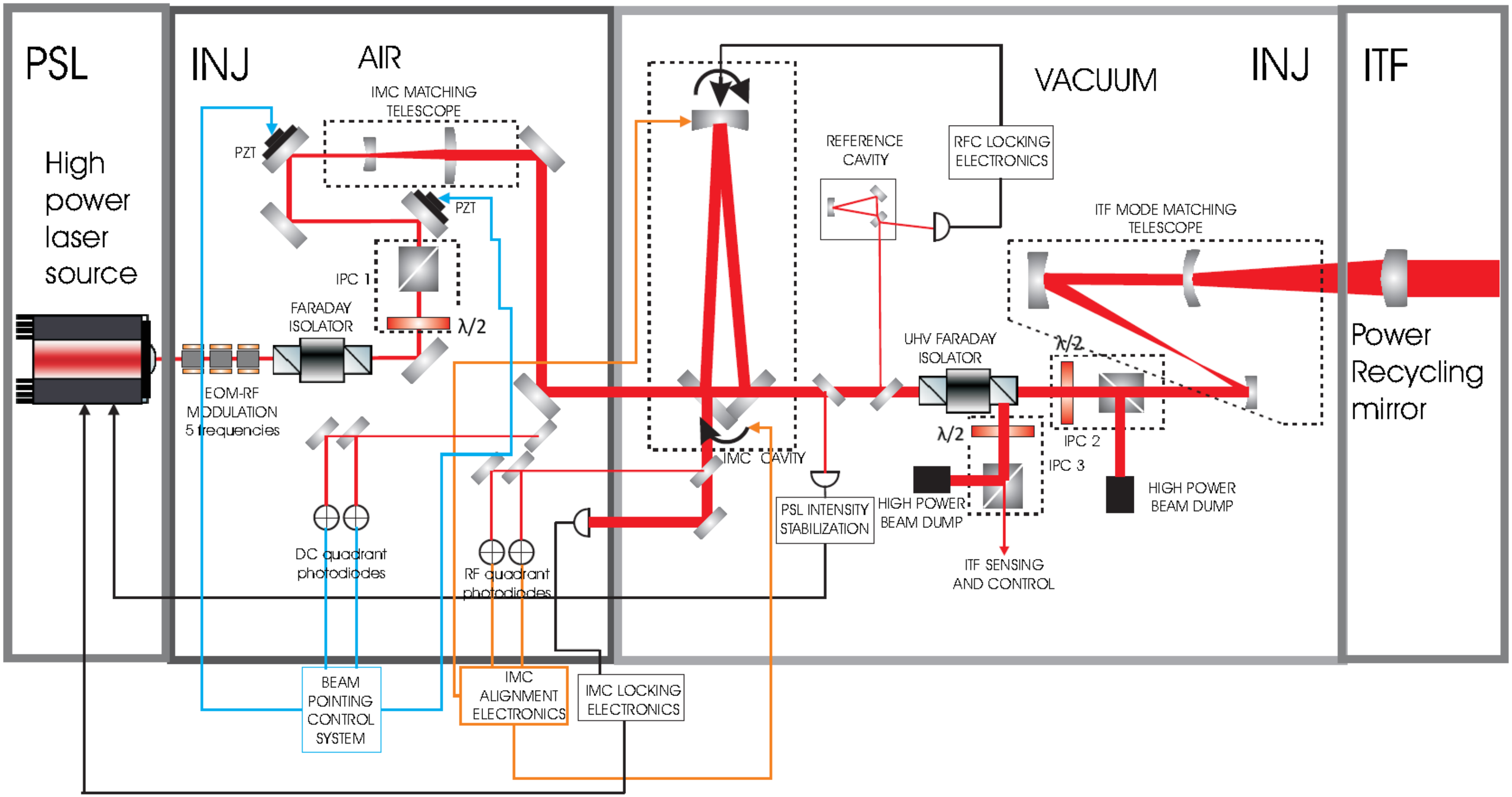

High magnification beam expander/reducer

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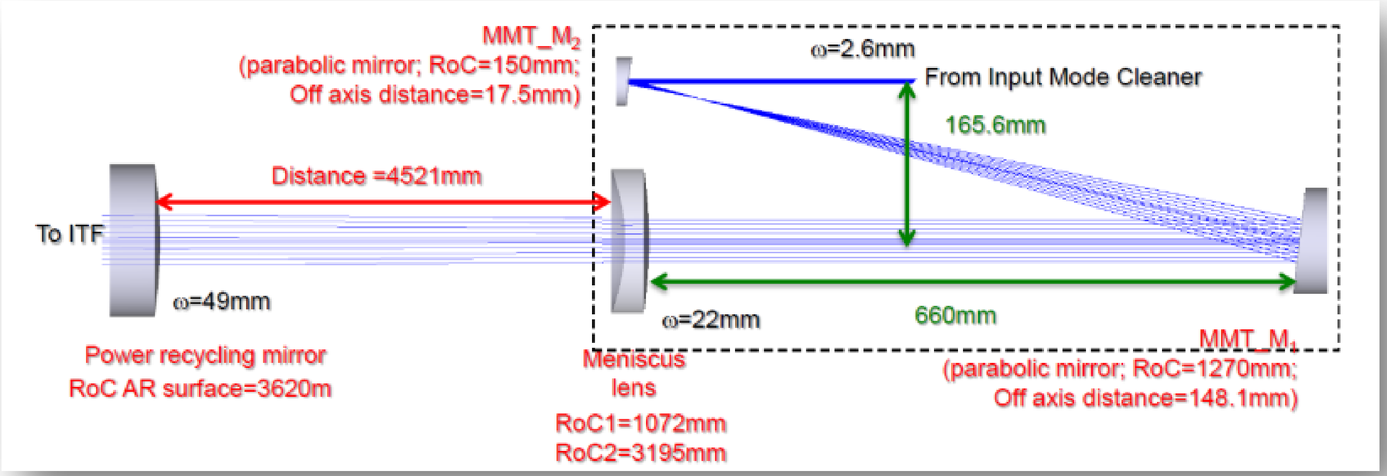
- Due to the large laser beam and the limited space available, we had to design an original and compact design for the launching telescope for Advanced Virgo. This is a catadioptric system.



[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).

High magnification beam expander/reducer

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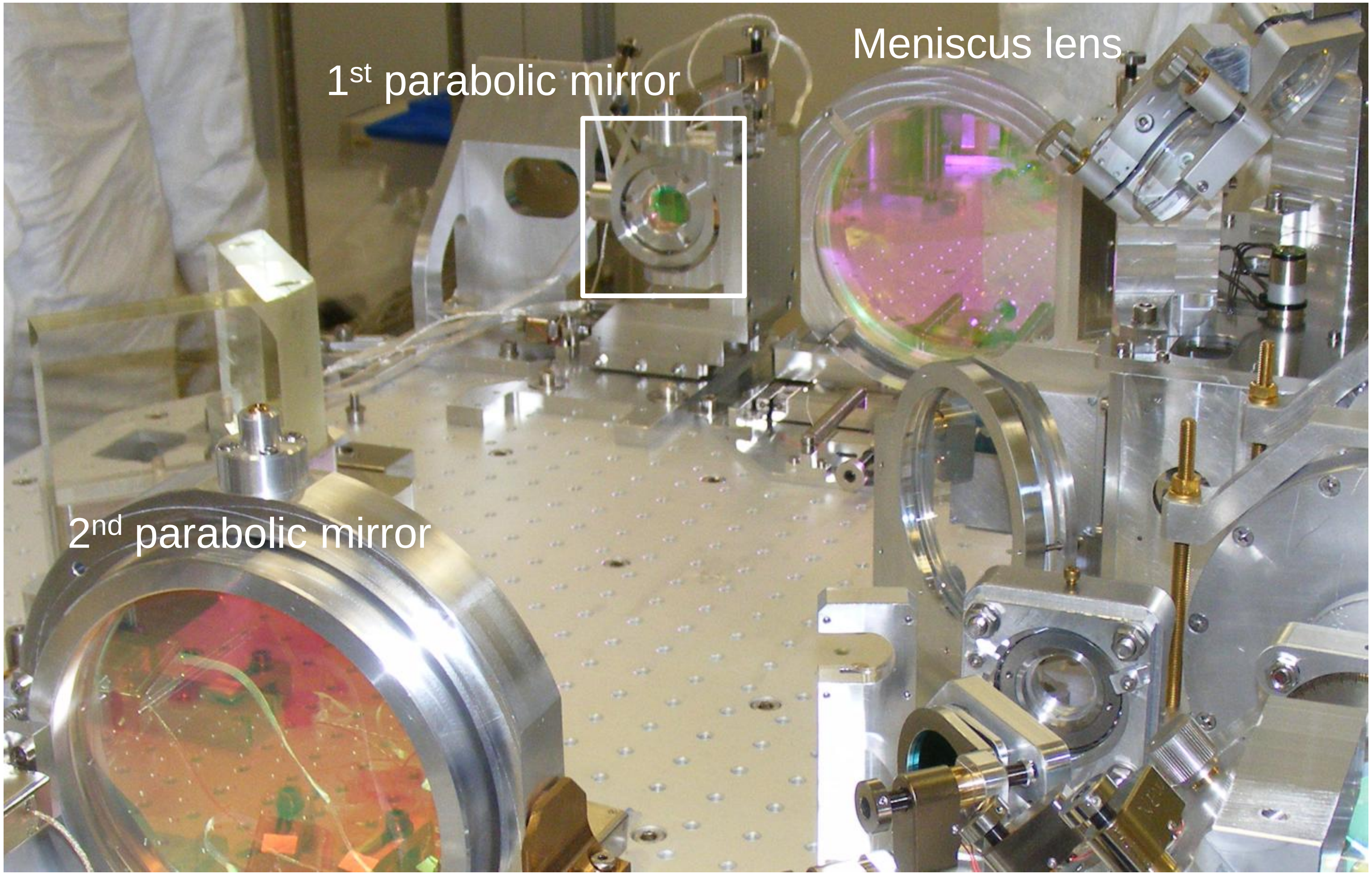

Stray-Light Control

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- The problem:
  - Stray light gave countless problems during past generation of GW detectors
  - A tiny amount of stray light coupling with the fundamental mode after “probing” the vibrations of infrastructures will bury any gravitational signal

- In design AdV, more than 70% of injected power will be lost in the arms…

➢ Need to control these wandering photons so that the spurious info carried by them contribute negligibly to sensitivity limit (10 times less than fundamental noises).

once emitted, a photon has to be caught!