Advanced Virgo Injection System & Stray-Light Control

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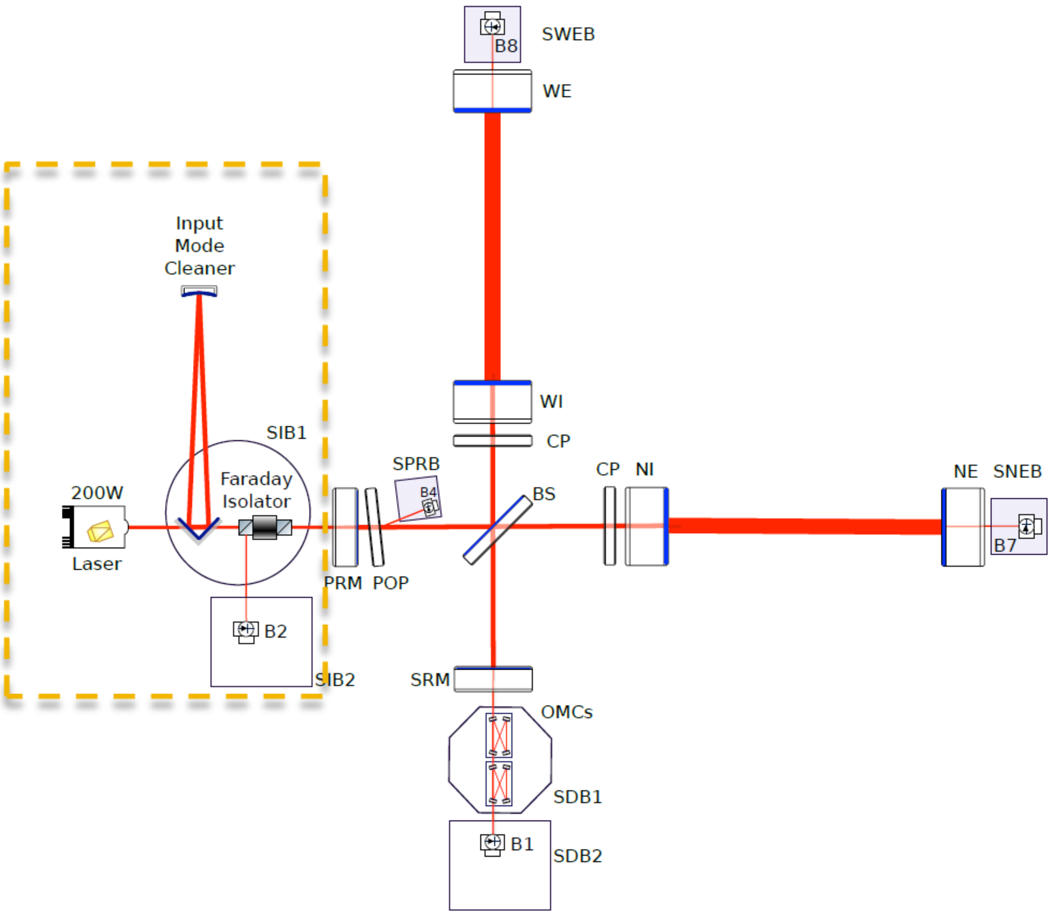
European Gravitational Observatory, Mar 21st, 2019

Outline

EGO - VIRGO

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



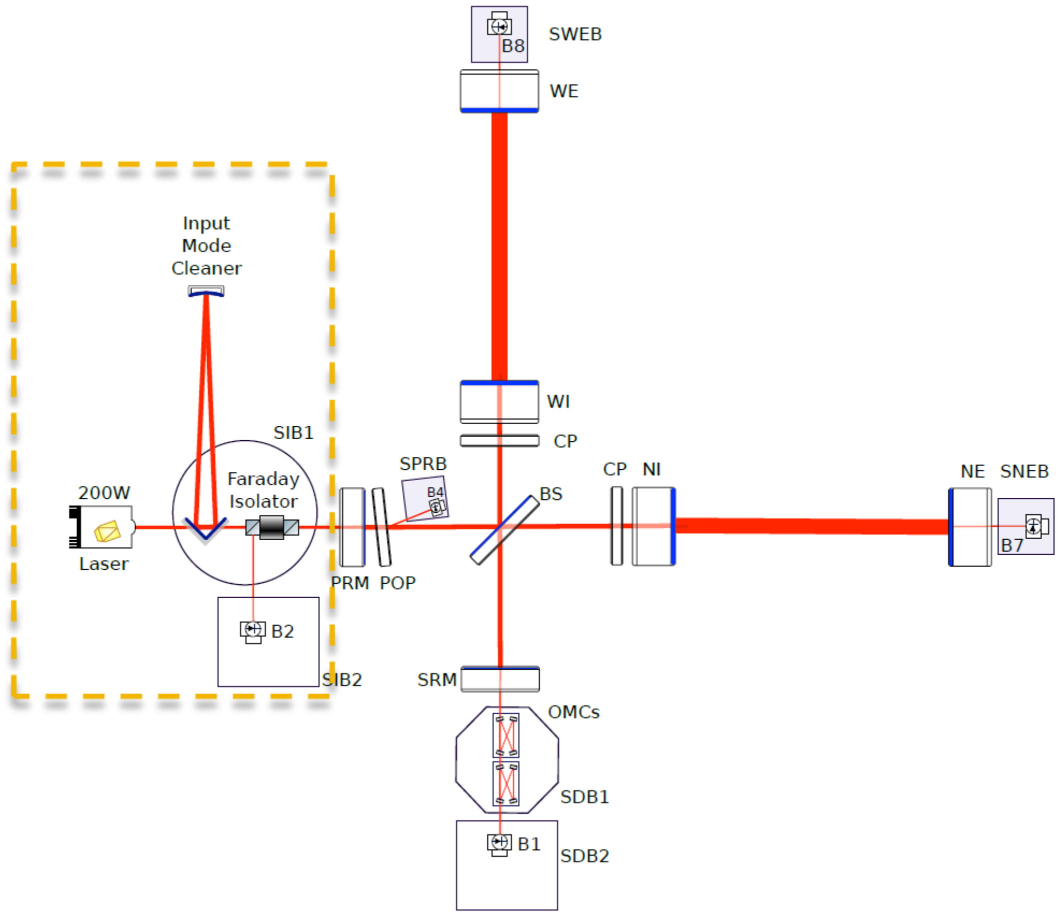
AdV optical layout

Outline

EGO - VIRGO

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

(Mostly based on work by E. Genin)



AdV optical layout

The Virgo/AdV (first phase) laser system

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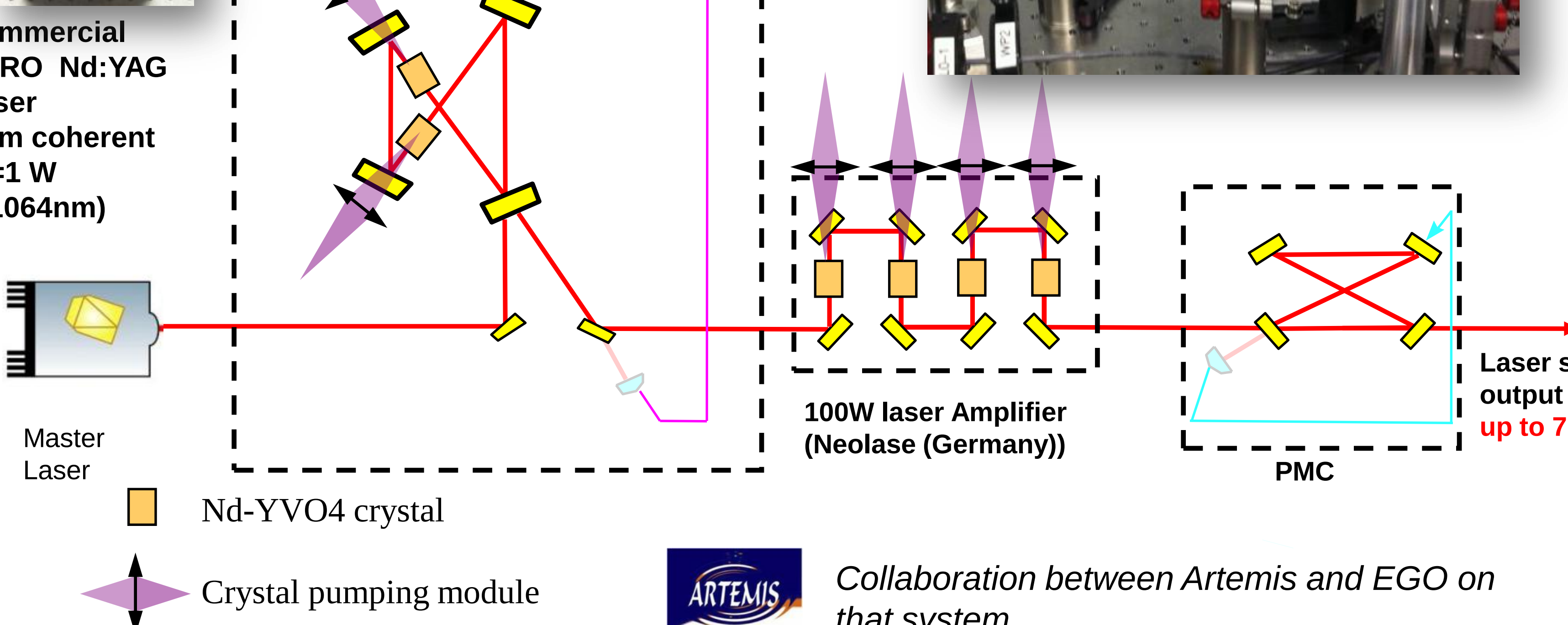
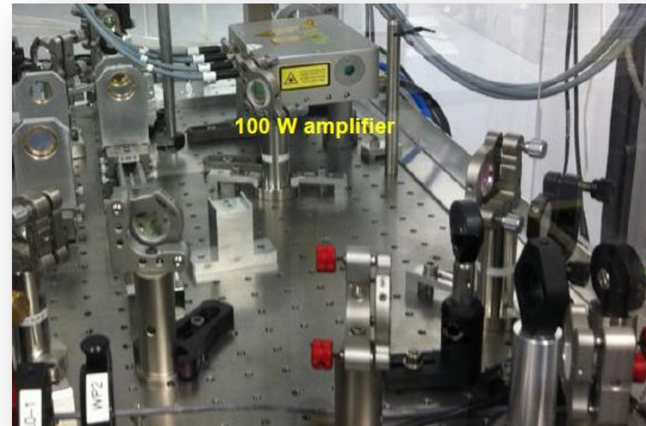
20 W Nd:YVO4 slave laser
(Laser Zentrum Hannover)
(injection-locked)

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





Collaboration between Artemis and EGO on that system

Laser source evolution

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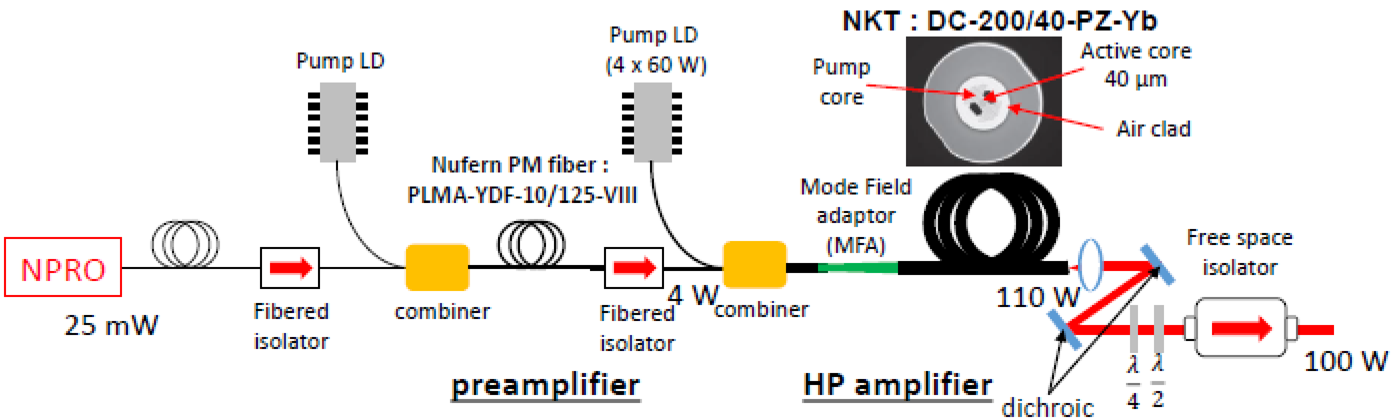
❑ Principle: sum coherently several laser amplifier modules up to get the required laser output power (200 W).

❑ The choice of the most reliable technology - either a solid state laser amplifier or a fiber laser amplifier - is still to be frozen



Credits: W Chaibi (Artemis)

ARTEMIS

Collaboration between Artemis and EGO on that system

Overview of the AdV INJ subsystem

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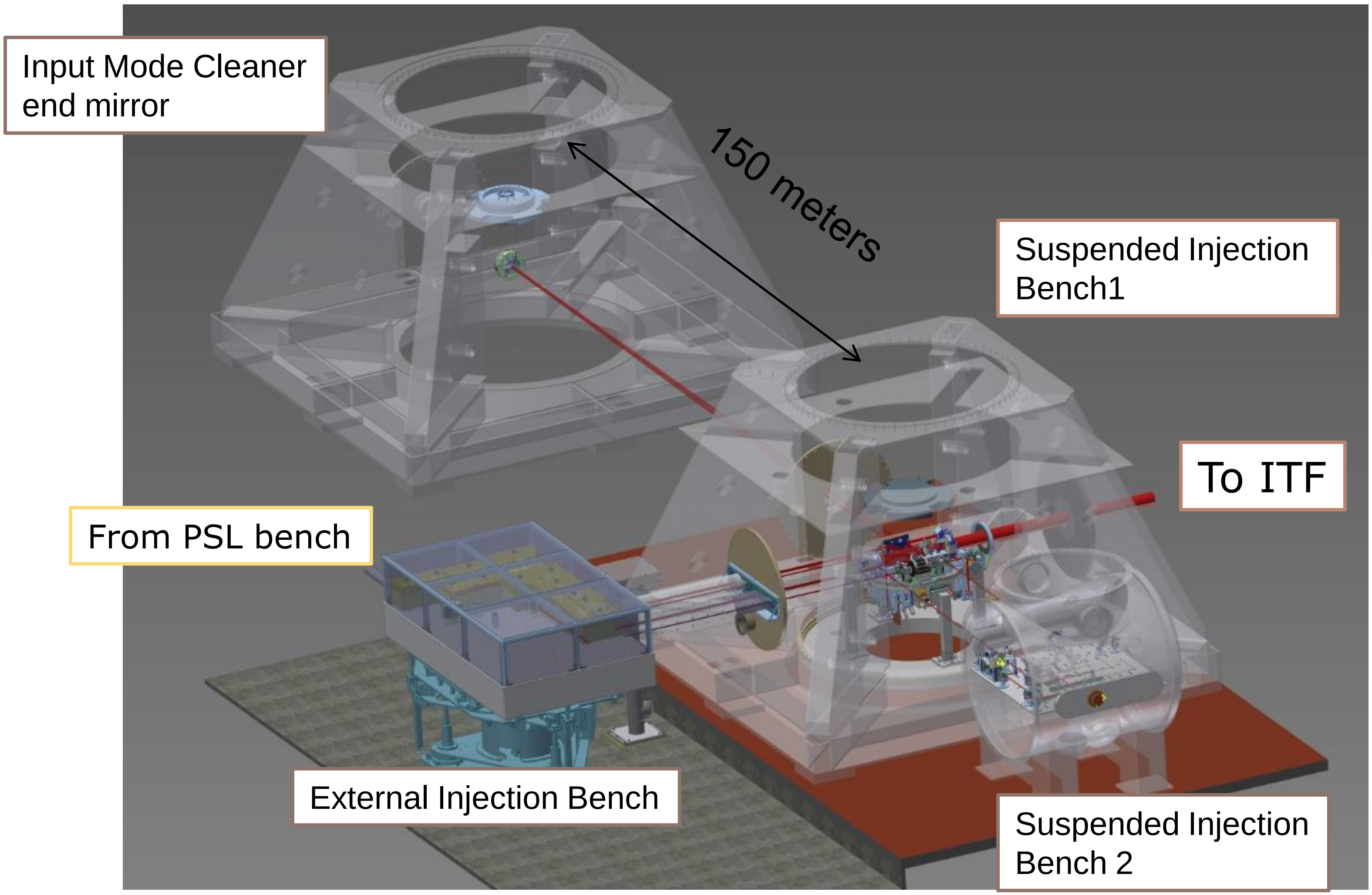

Overview of the AdV INJ subsystem

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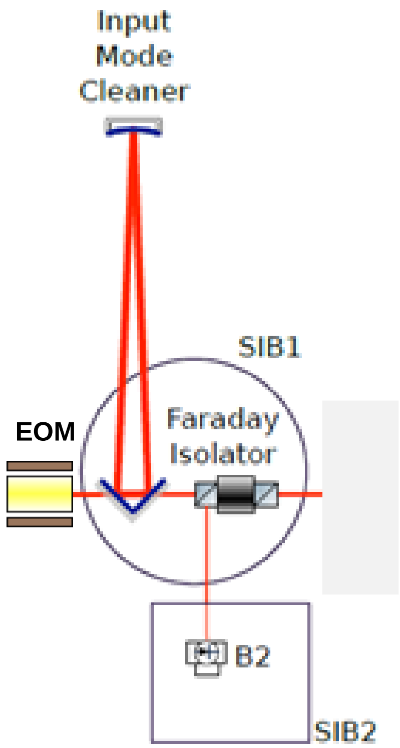
The Injection system (INJ) of AdV takes care of the optics downstream of the high power laser, and of the interface of these optics with the laser and the Interferometer.



➢ 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

AdV INJ subsystem: simplified scheme with control loops

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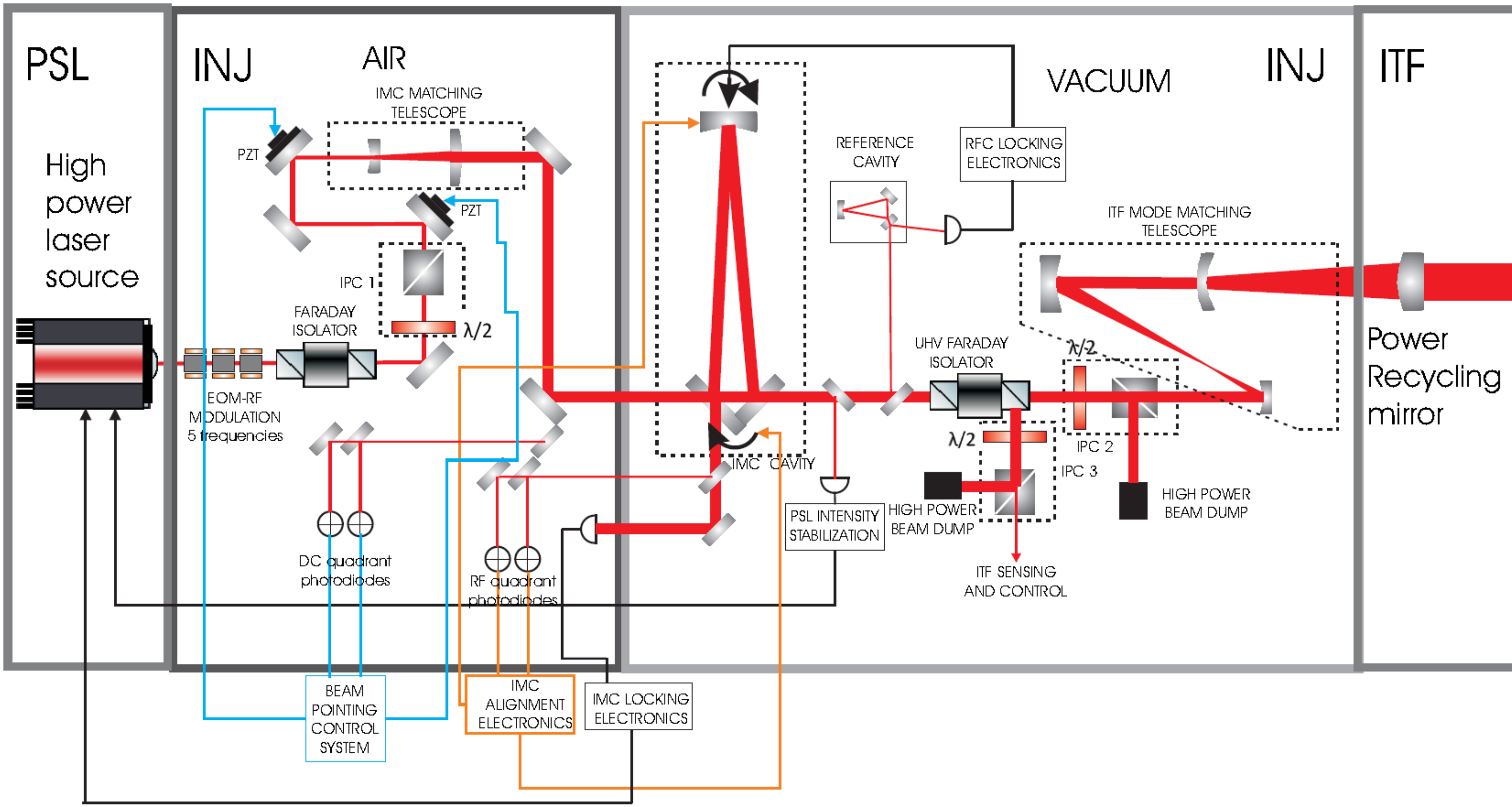

AdV INJ subsystem: simplified scheme

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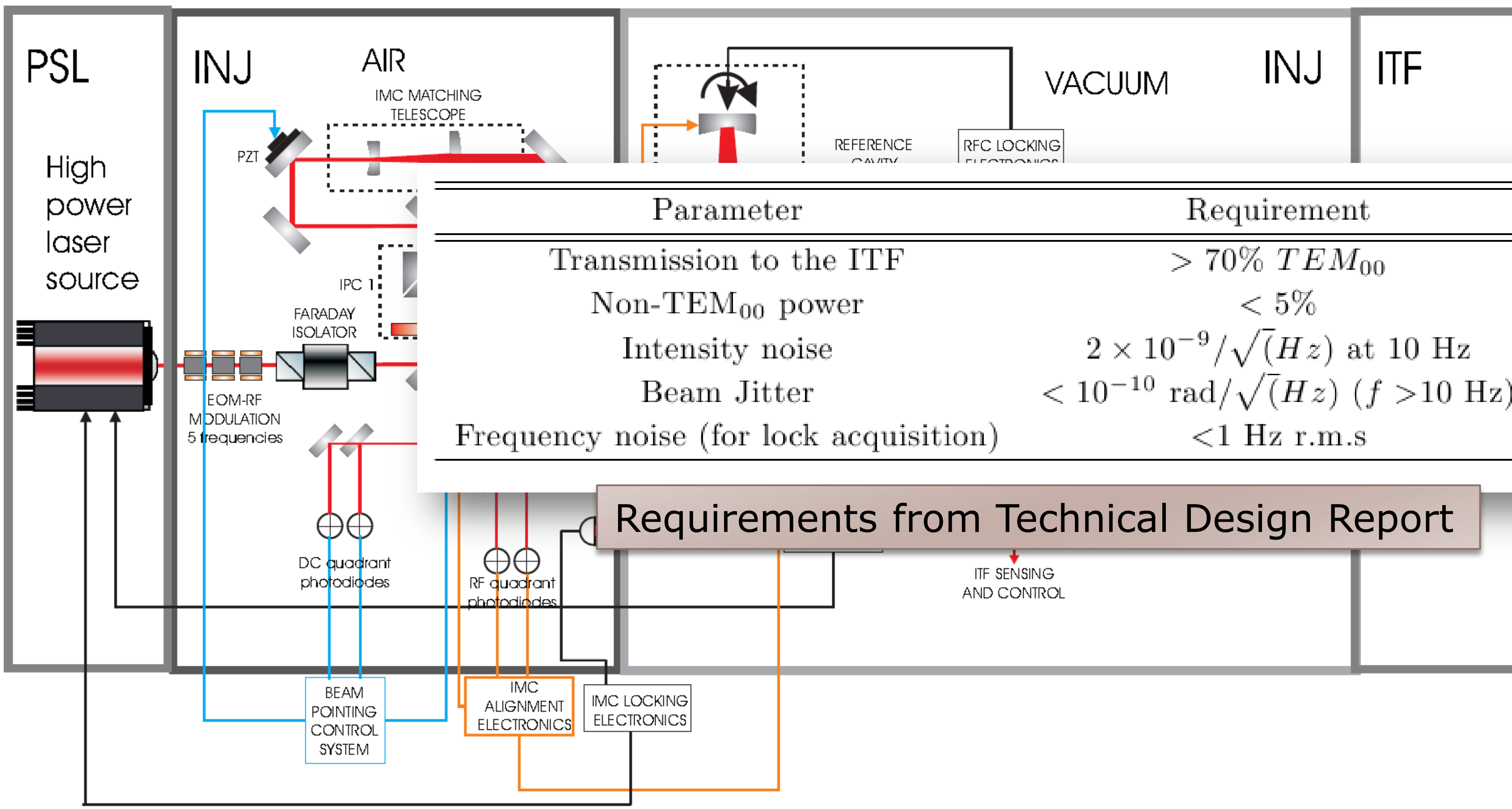

Parameter	Requirement
Transmission to the ITF	$> 70\%\ TEM_{00}$
Non-TEM_{00} power	$< 5\%$
Intensity noise	$2 \times 10^{-9}/\sqrt{(Hz)}$ at 10 Hz
Beam Jitter	$< 10^{-10}$ rad$/\sqrt{(Hz)}$ (f >10 Hz)
Frequency noise (for lock acquisition)	<1 Hz r.m.s

Requirements from Technical Design Report

Complex optical systems design and realization

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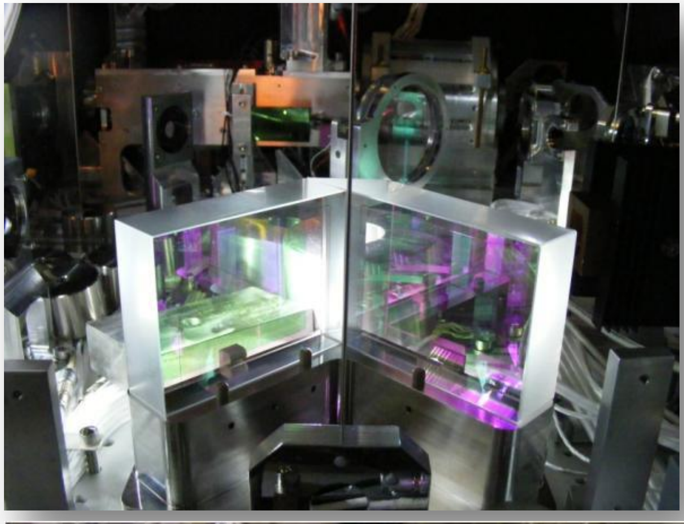

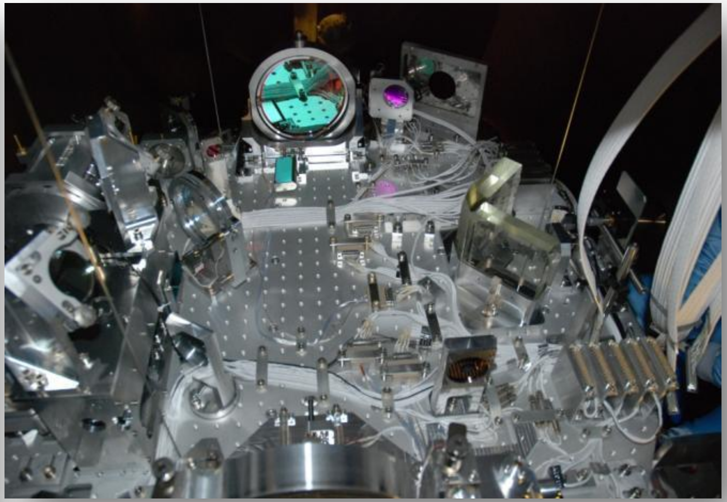

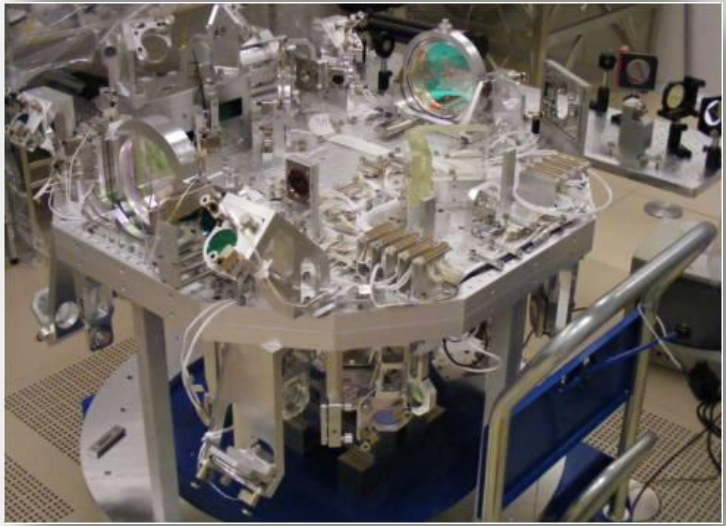

→ Ultra high vacuum compatible optical bench used to inject the Laser beam in the Virgo Interferometer.
Used also to pre-stabilize the laser frequency
(a rigid reference cavity (RFC) is below this bench)

Complex optical systems design and realization

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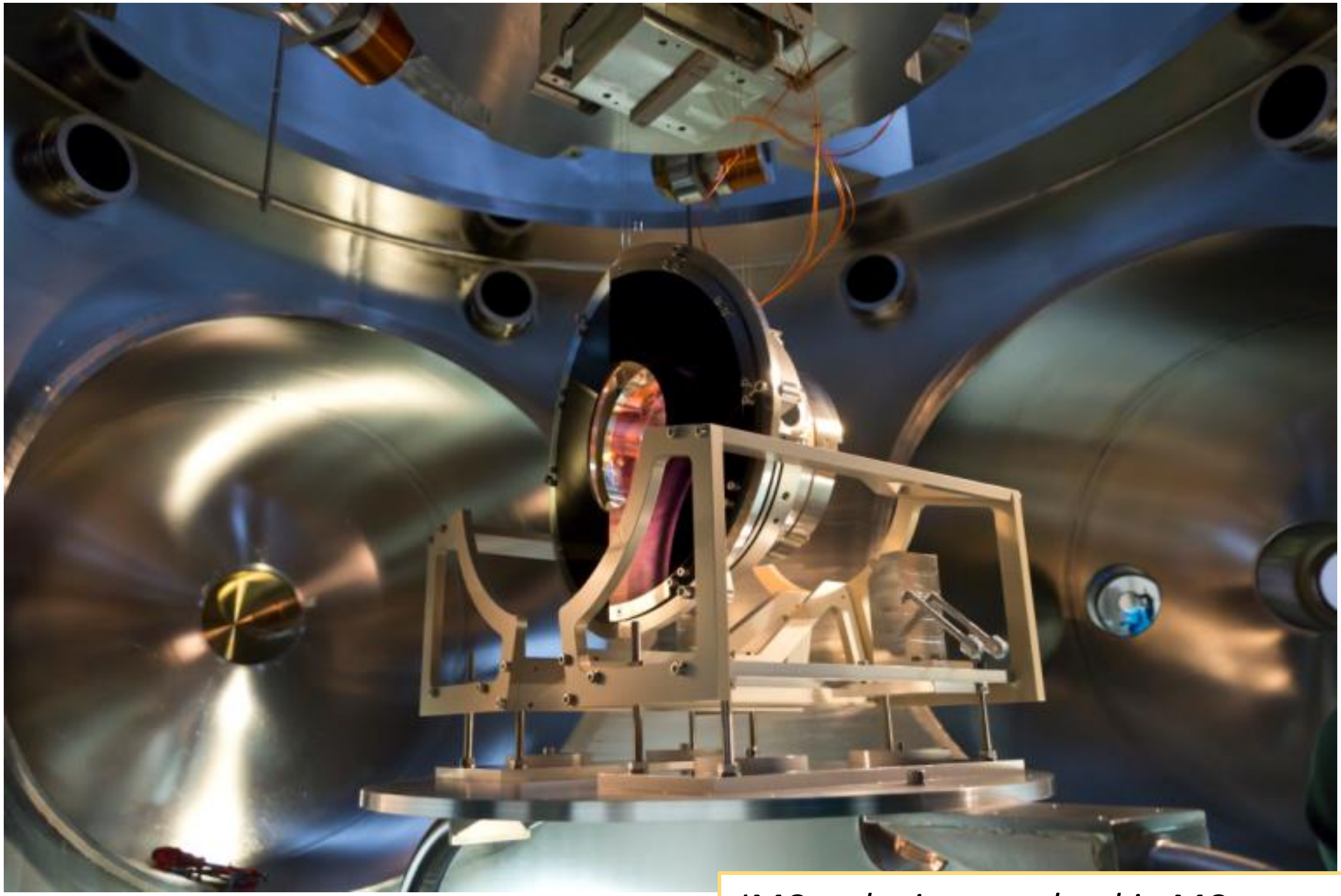

IMC end mirror payload in MC tower

Development of custom components

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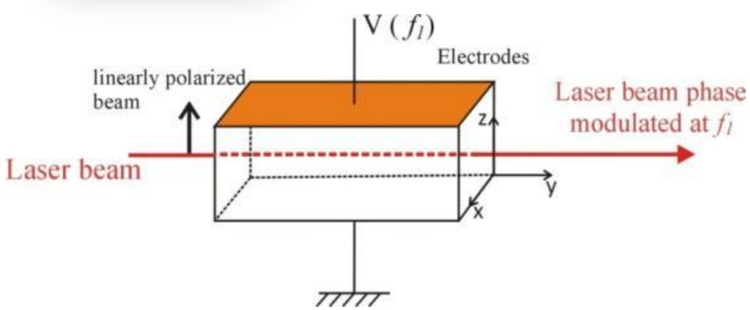
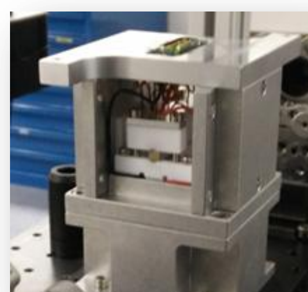
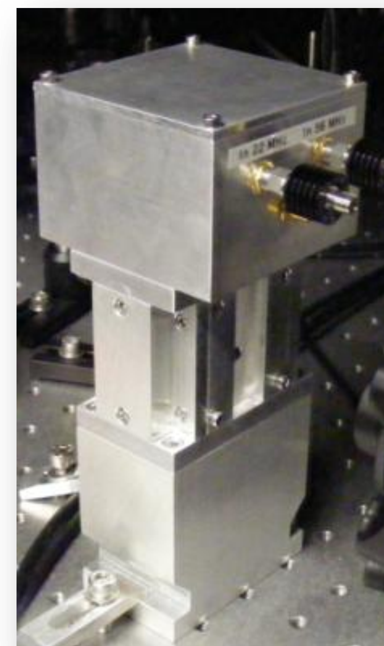
- high power compatible electro-optic modulators (EOM)
  - Requirements:
    - Withstand 200W CW laser power @1064nm.
    - Limited thermal lensing effect (low absorption crystal used (RTP)).
    - Maximum modulation depth = 0.2 rad.
    - Low phase noise (mostly related to the RF oscillator).
    -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

Electro optic material chosen:
Rubidium Titanyle Phosphate – $RbTiOPO_4$







2-frequencies EOM

Development of custom components

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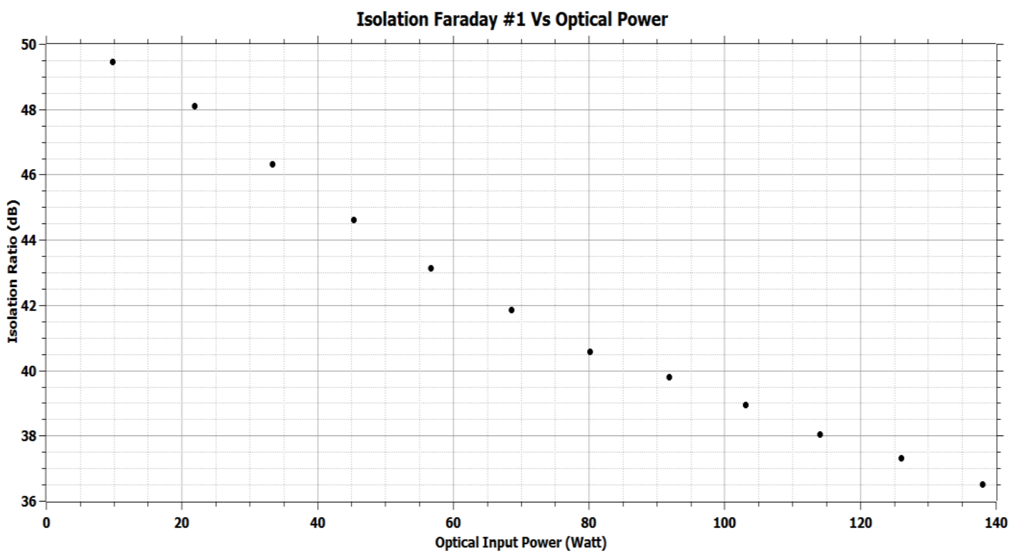
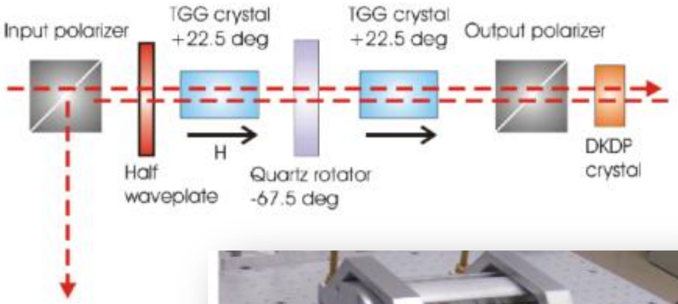
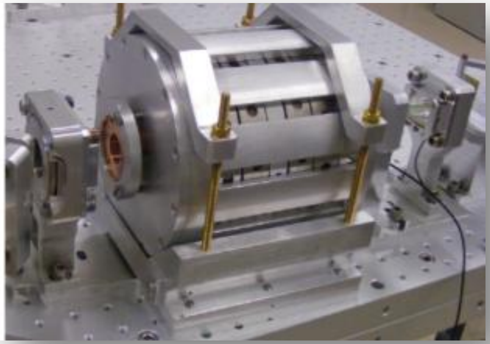
❑ high power, ultra-high vacuum compatible Faraday isolator (FI)

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







Reference:

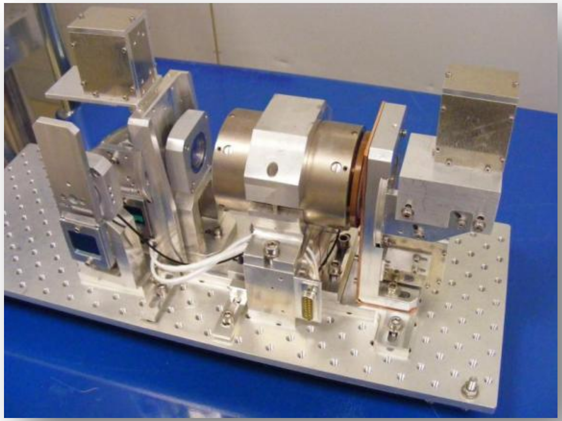
[1] O. Palashov, D. Zheleznov, A. Voitovich, V. Zelenogorsky, E. Kamenetsky, E. Khazanov, R. Martin, K. Dooley, L. Williams, A. Lucianetti, V. Quetschke, G. Mueller, D. Reitze, D. Tanner, E. Genin, B. Canuel, and J. Marque, High-vacuum compatible high-power Faraday isolators for gravitational-wave interferometers,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

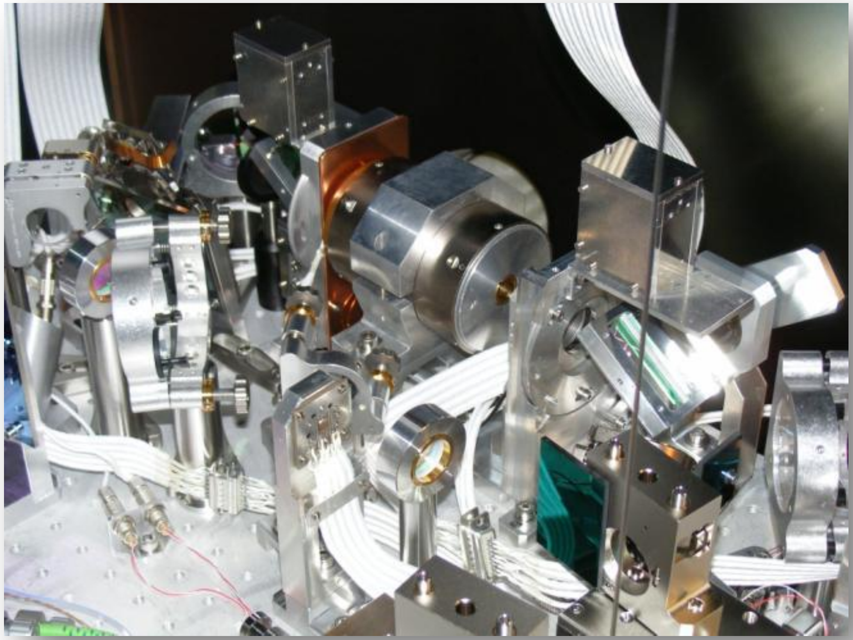
Development of custom components

EGO - VIRGO

❑ 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)

High magnification beam expander/reducer

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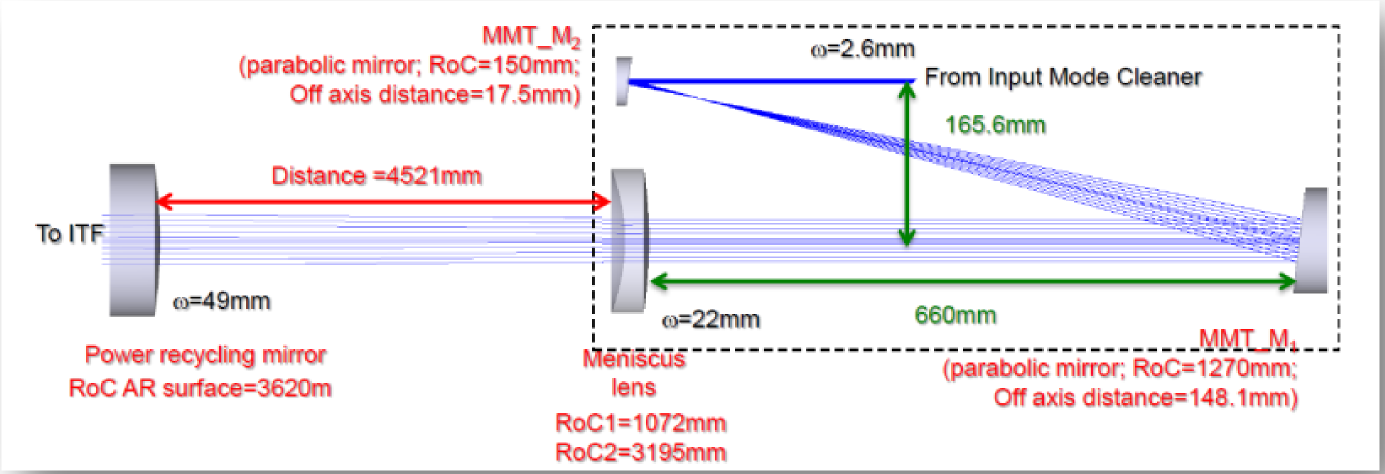
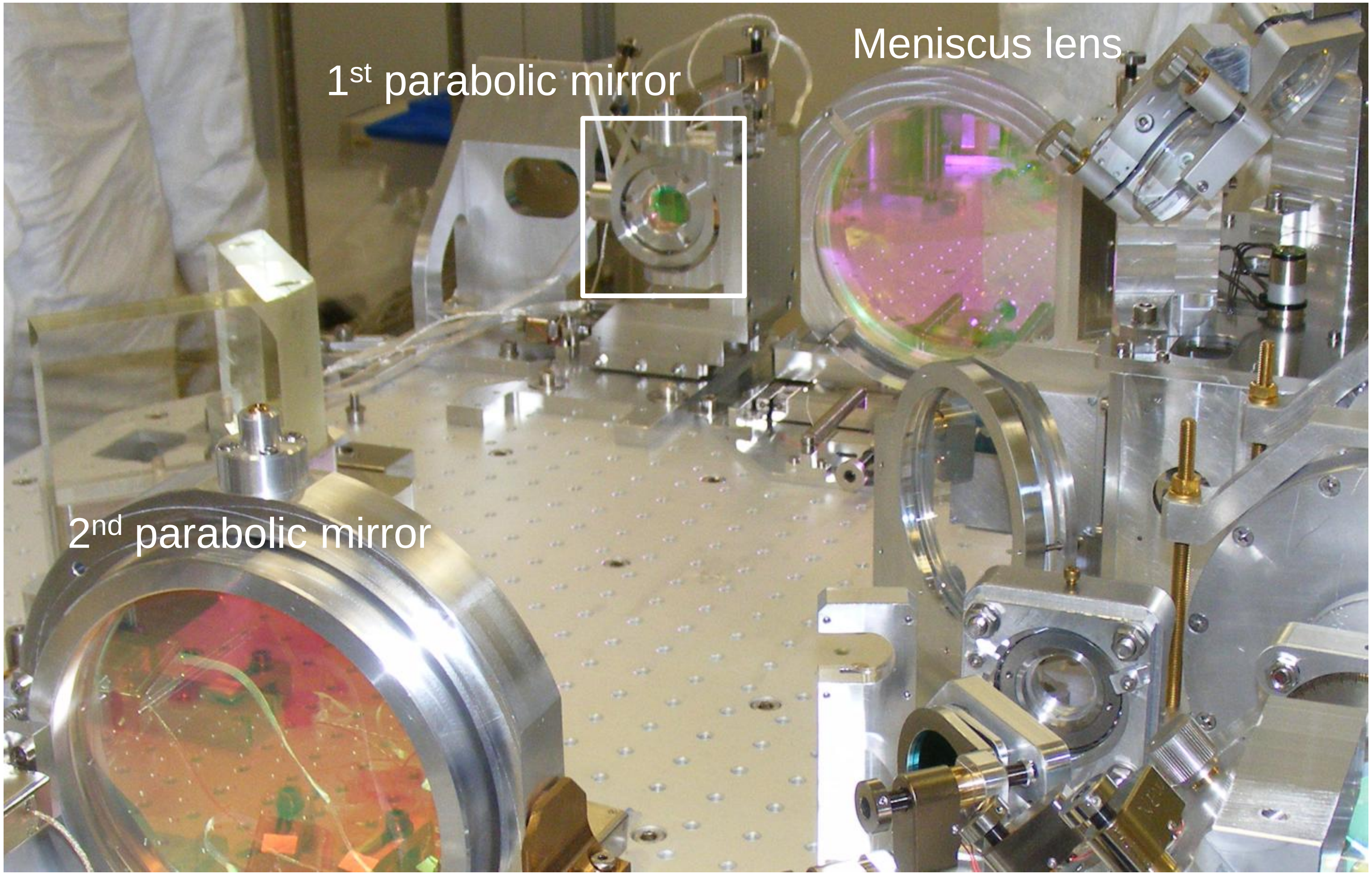
- Due to the large laser beam and the limited space available, we had to design an original and compact design for the launching telescope for Advanced Virgo. This is a catadioptric system.



[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

EGO - VIRGO



Stray-Light Control

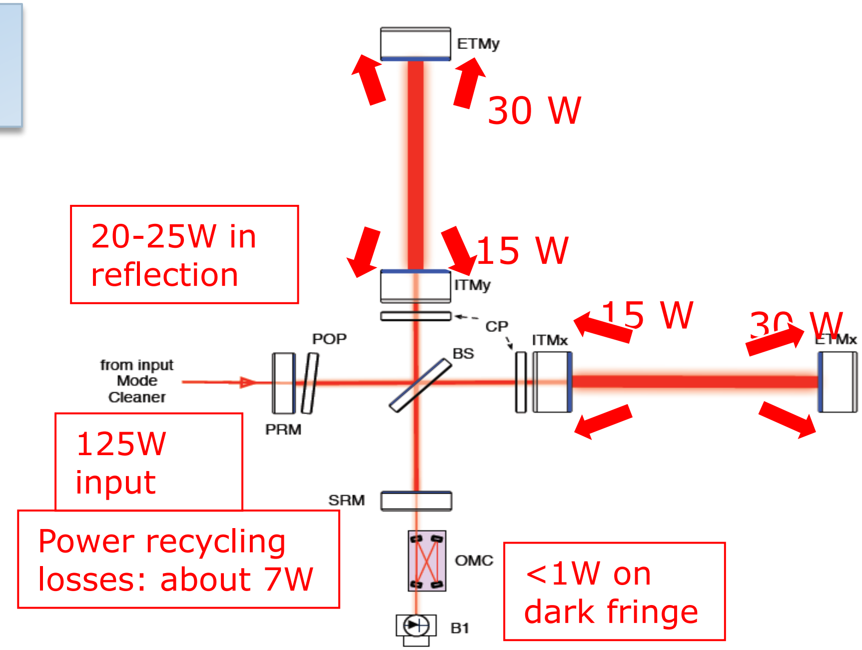
❑ The problem:

- 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!



Stray-Light Control

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

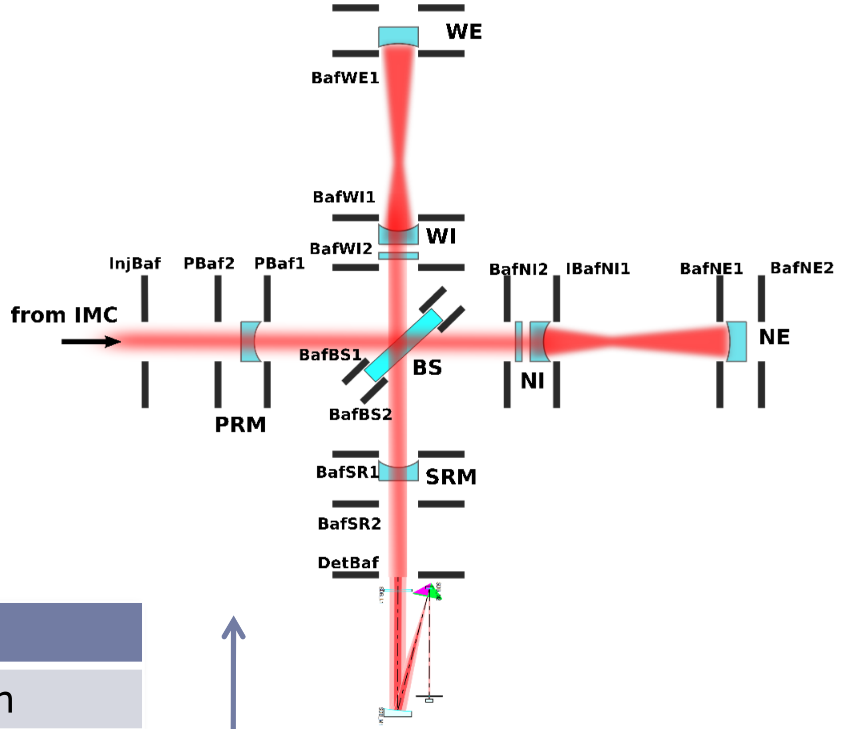
➢ Selection of material driven by:

- 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

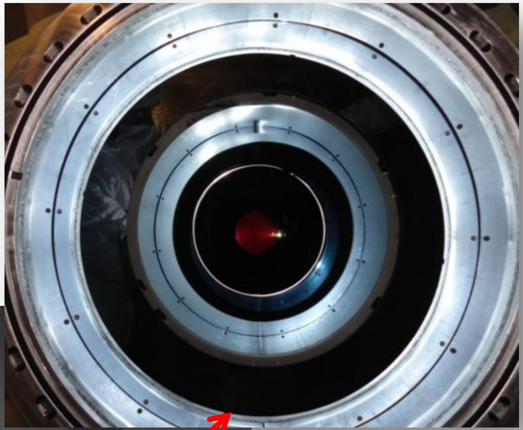
Cost increase

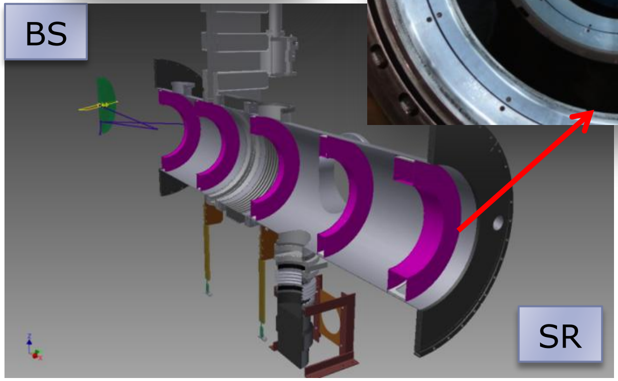


See report: VIR-0482A-14
https://tds.virgo-gw.eu/ql/?c=10539

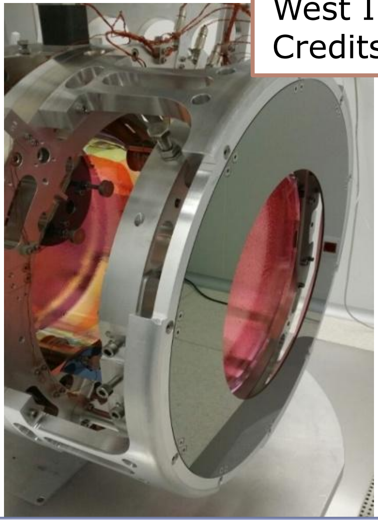
Stray-Light Control

- Central Interferometer baffles

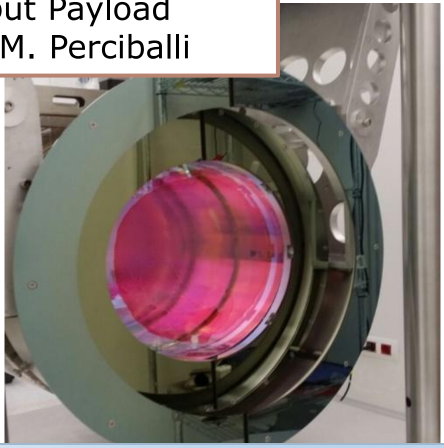




West Input Payload
Credits: M. Perciballi



Back baffle (facing BS)



Front baffles (facing arm)

- Test-mass baffles

- Cryogenic trap baffles

Thank you

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