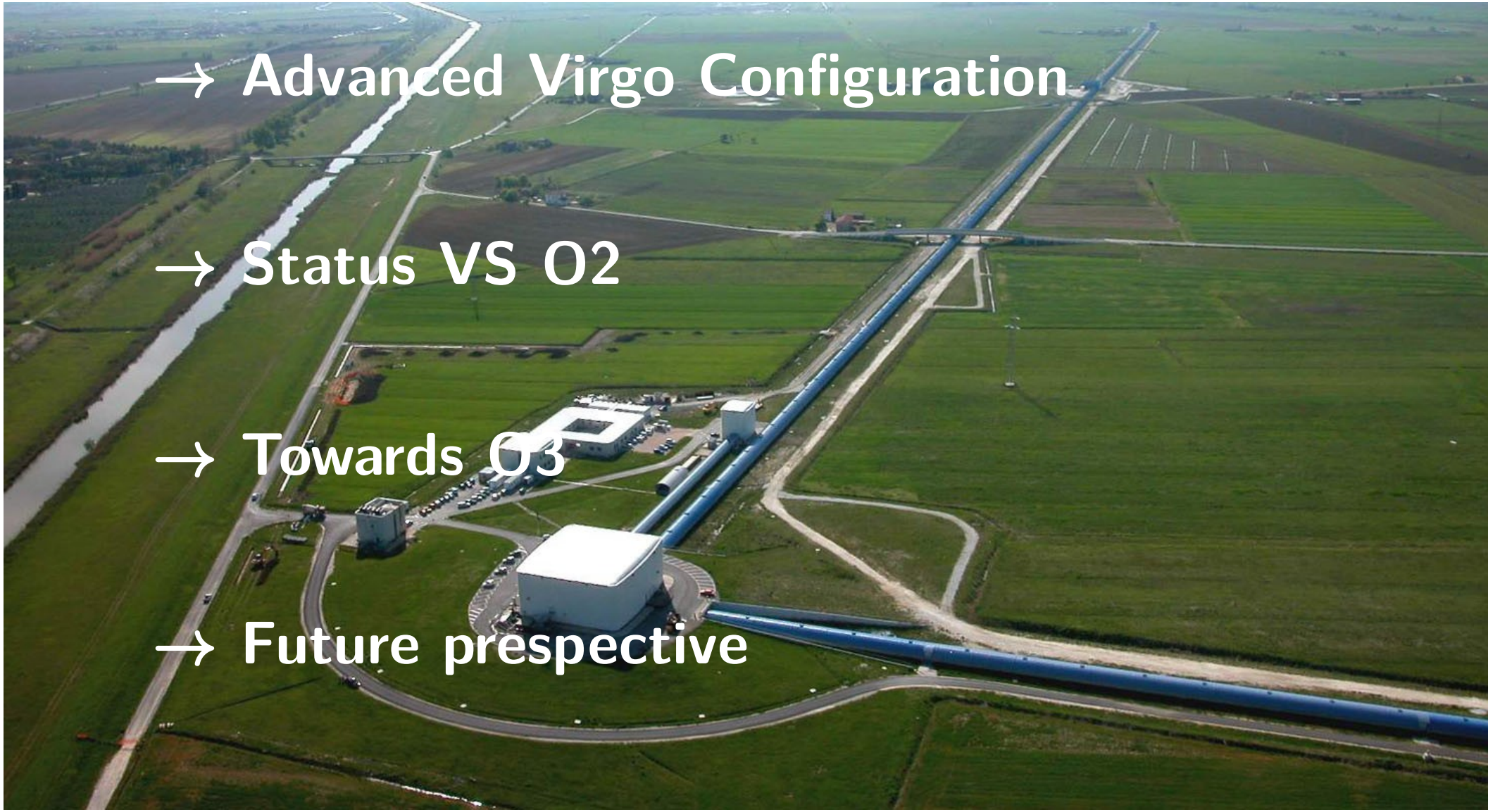
Status of AdVirgo before the new Observation Run O3

Martina De Laurentis for the

Collaboration

18-22 June 2018 Hotel Vittorio,
Portopalo di Capo Passero (SR) - Italy

Outline



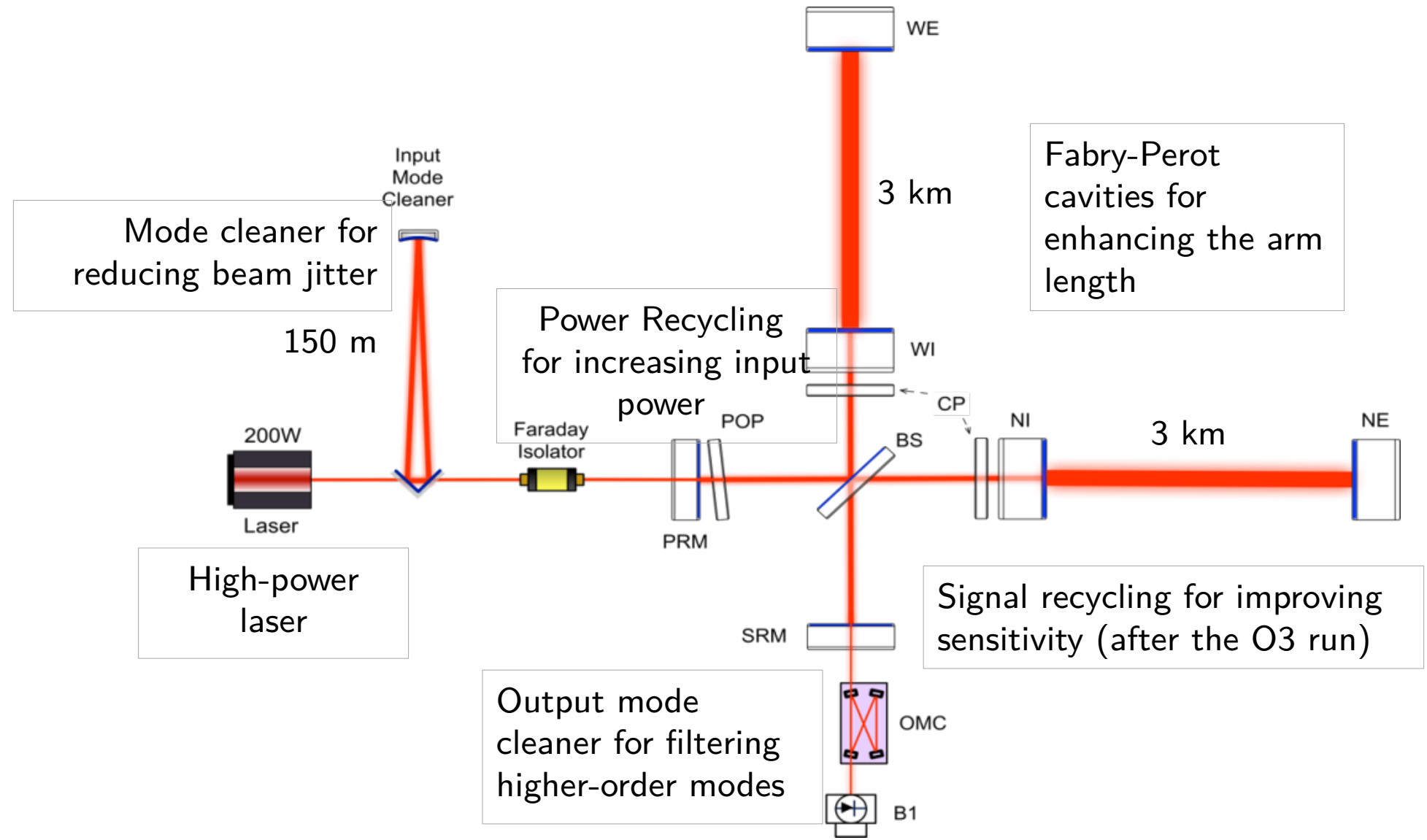
→ Advanced Virgo Configuration

→ Status VS O2

→ Towards O3

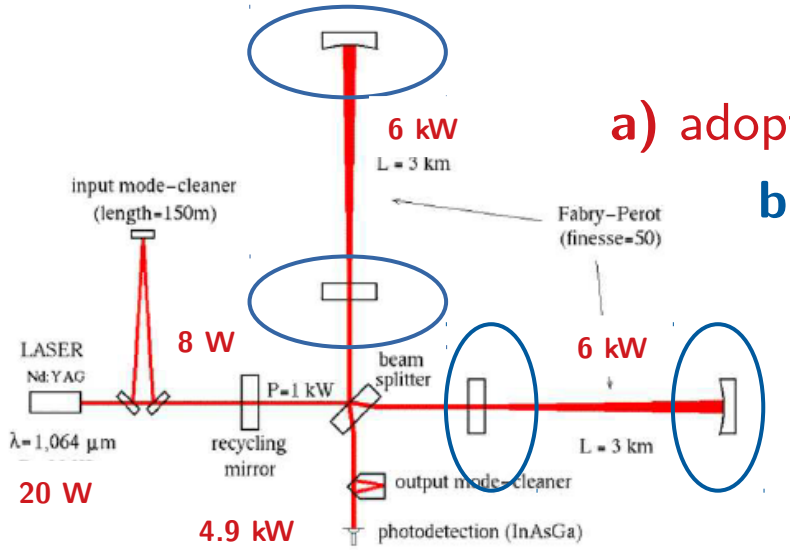
→ Future prespective

Advanced Virgo configuration

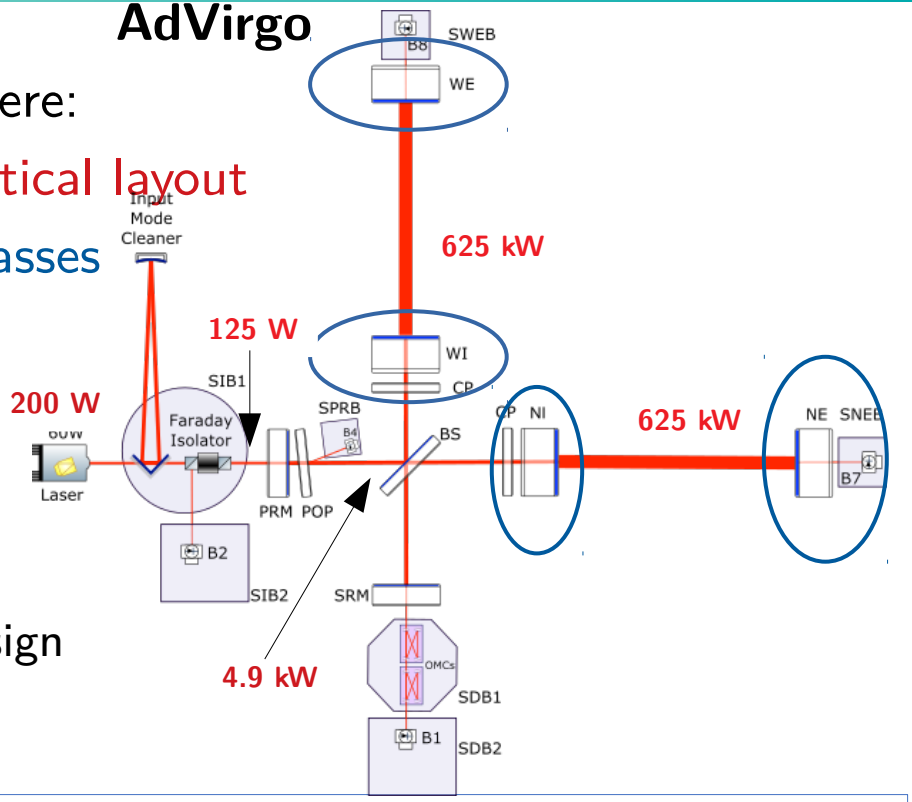


Advanced Virgo VS Virgo +

Virgo



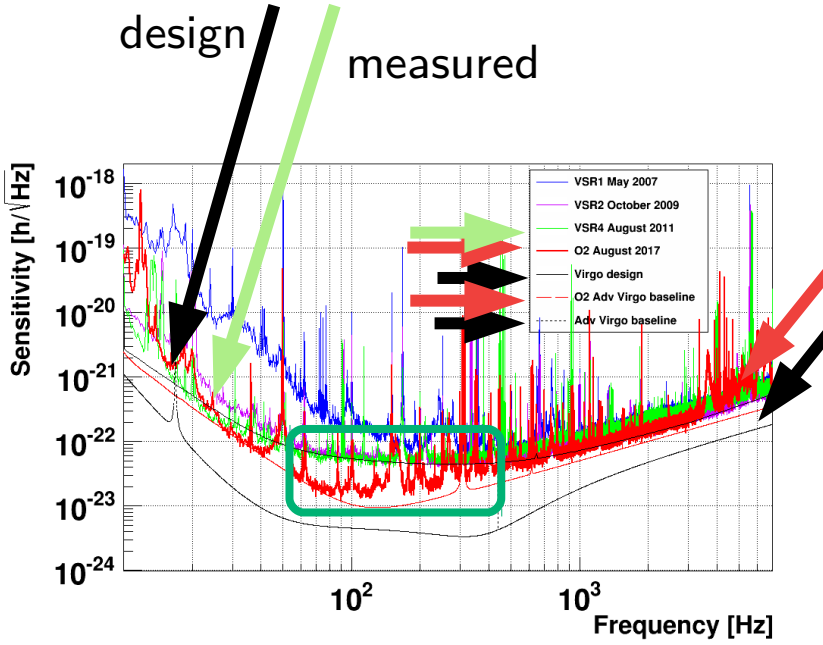
AdVirgo



Main features were:

a) adoption of a new optical layout

b) heavier test masses



- x10 Optical Power at Laser output
- **x2 Mass of 3km FP cavity mirrors**
- **x2.5 larger beams**
- **Higher quality substrates (<0.5 nm Roughness)**
- **Improved coatings (<0.5 ppm, scattering <10ppm)**
- **x3 Higher Finesse**
- Improved Thermal Compensation System (Ring Heater, Hartaman sensors, phase cameras)
- **Improved Stray Light reduction**
- Signale Recicling

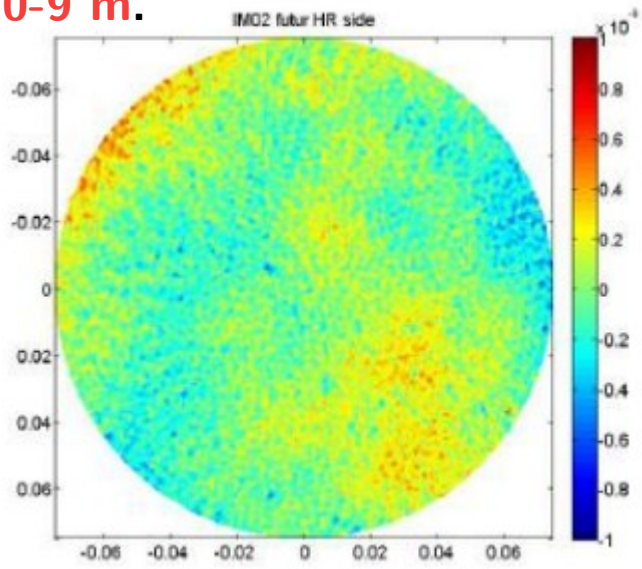
O2

Many minor (*and not – ex. SR*) AdV features were not implemented yet.

Advanced Virgo Configuration

Beam Splitter

SiO2 mirrors, **350 mm in diameter**, **200 mm thick**, with a **residual roughness < 0,5 x 10-9 m**.



Test Mass

Heavier mirrors 42 kg in weight
(~2x heavier than in Virgo+) to reduce the effect of the radiation pressure,
suspended to
monolithic suspensions SiO2 fibers 400 µm in diameter
.

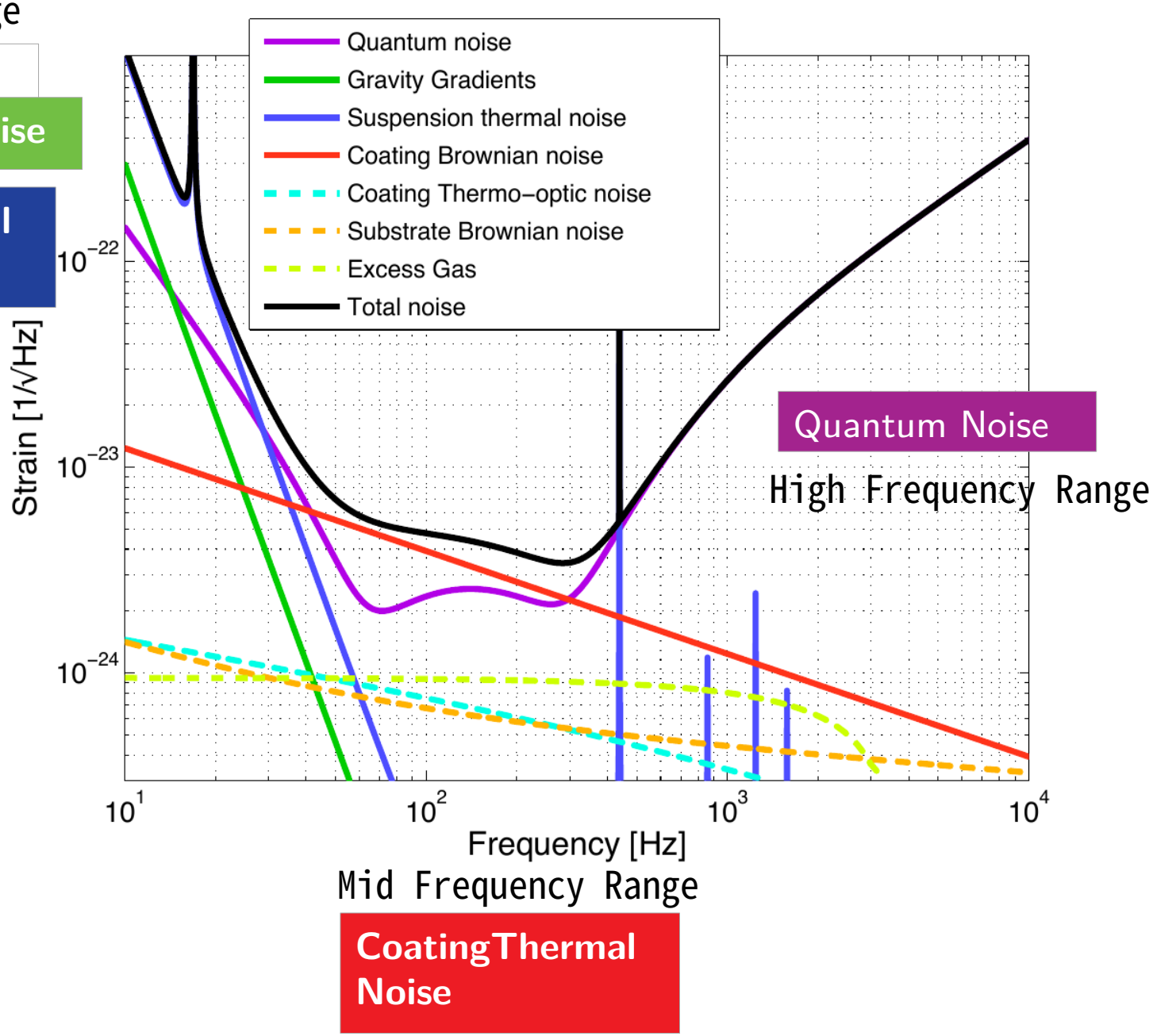
Advanced Virgo: limiting noise at different frequencies

Low Frequency Range

Seismic vibrations

Newtonian Noise

Suspension Thermal Noise



Quantum Noise

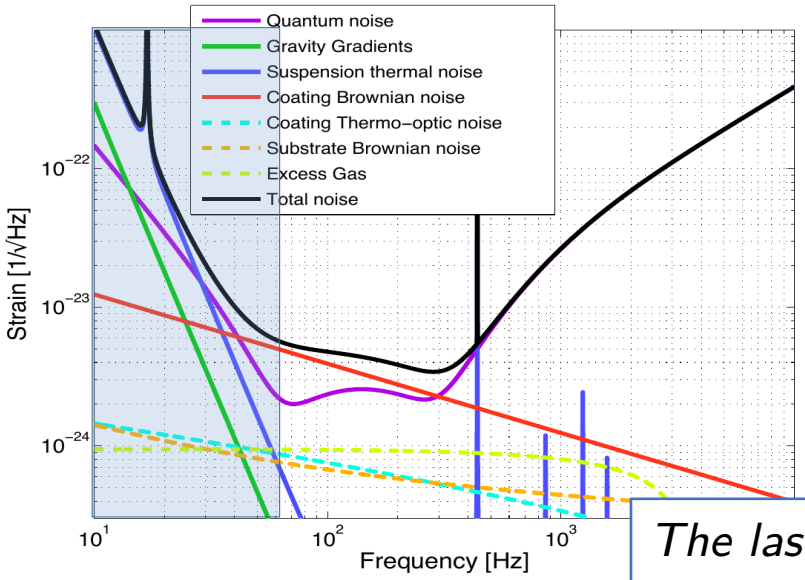
High Frequency Range

Mid Frequency Range

CoatingThermal Noise

Advanced Virgo configuration

Low Frequency Range:



Seismic vibrations

Newtonian Noise

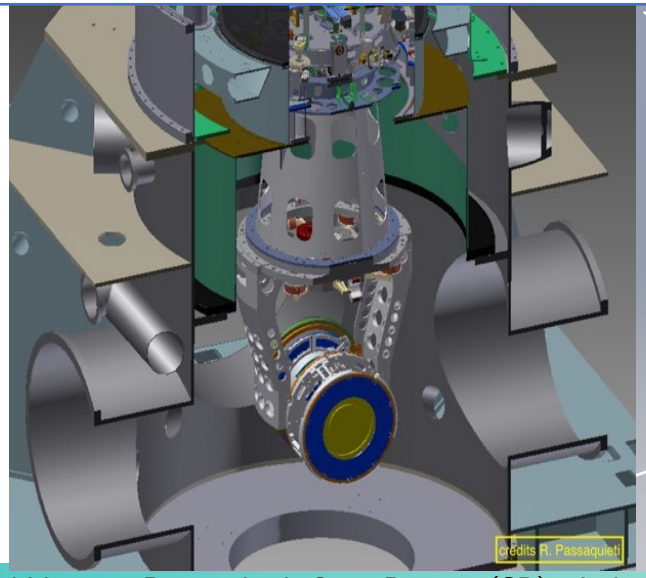
Suspension Thermal Noise

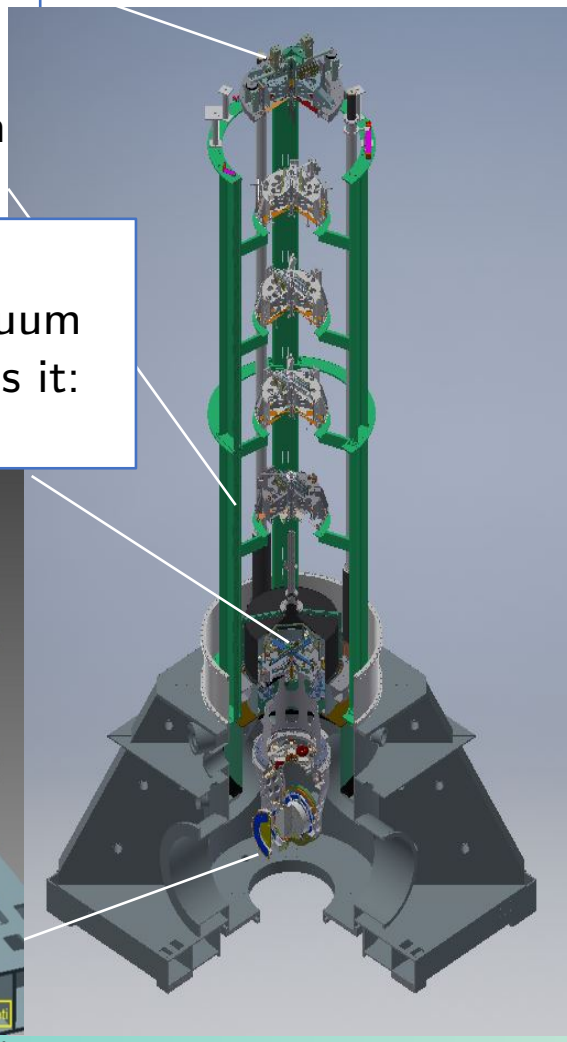
The first 5 stages of AdV Super-Attenuator (horizontal and vertical) are the same as in initial Virgo.

The last filter of the Super attenuator, prolonged downwards, is in the same vacuum environment of the payload and surrounds it: the "actuation cage".

Seismic isolation:

- Virgo superattenuators compatible with AdV specs;
- adapted for new payload (added mass and complexity)
- new electronics

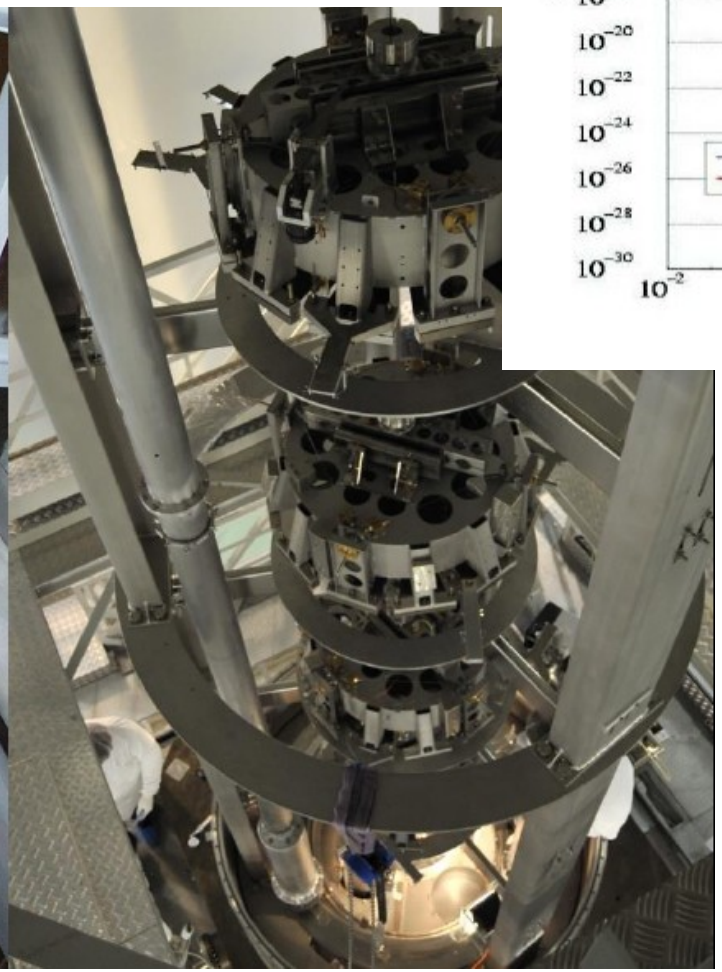


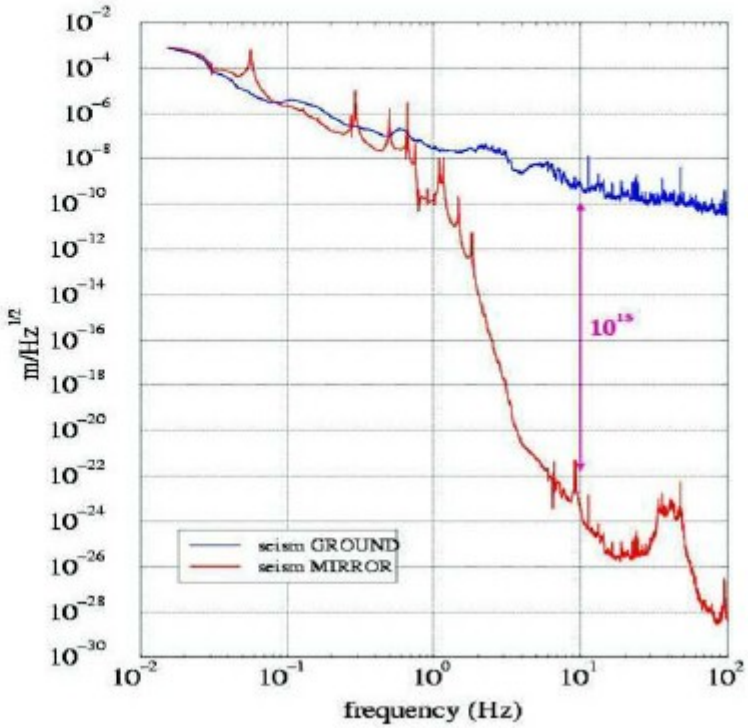


Advanced Virgo Configuration

Bottom view

Top view





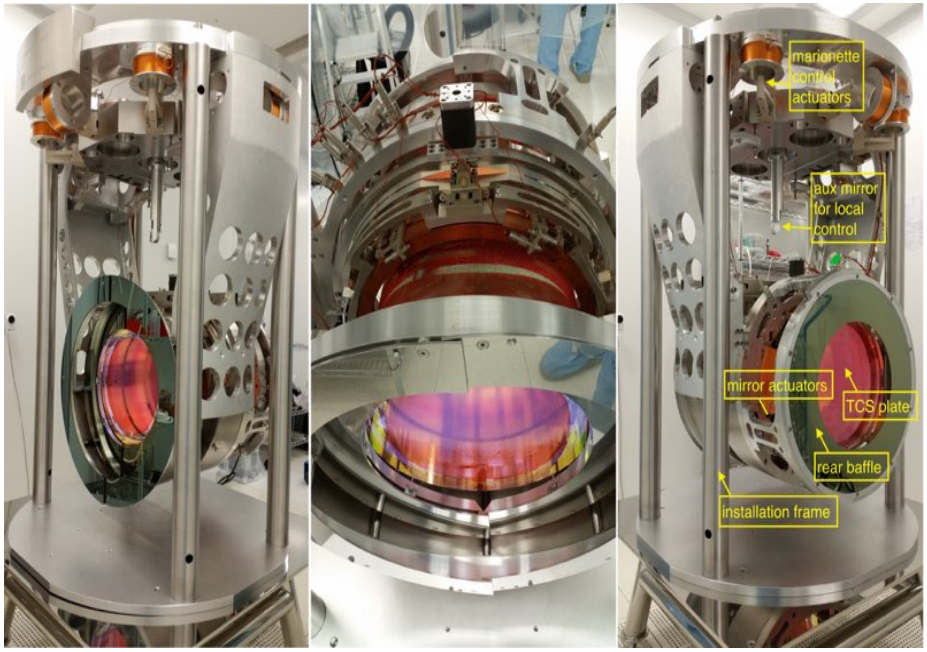
Passive filtering above 10 Hz

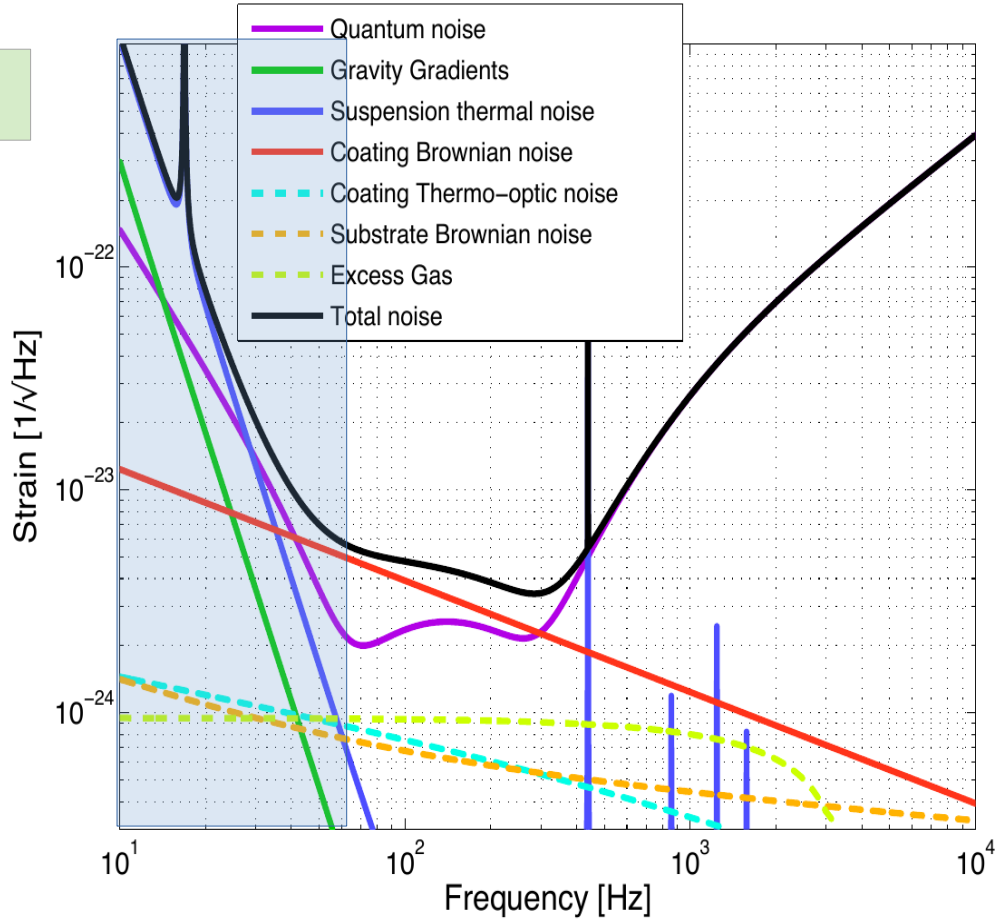
Advanced Virgo configuration

Low Frequency Range: Seismic vibrations

Newtonian Noise

Suspension Thermal Noise





AdV quasi-monolithic suspensions, same successful design adopted since 2009

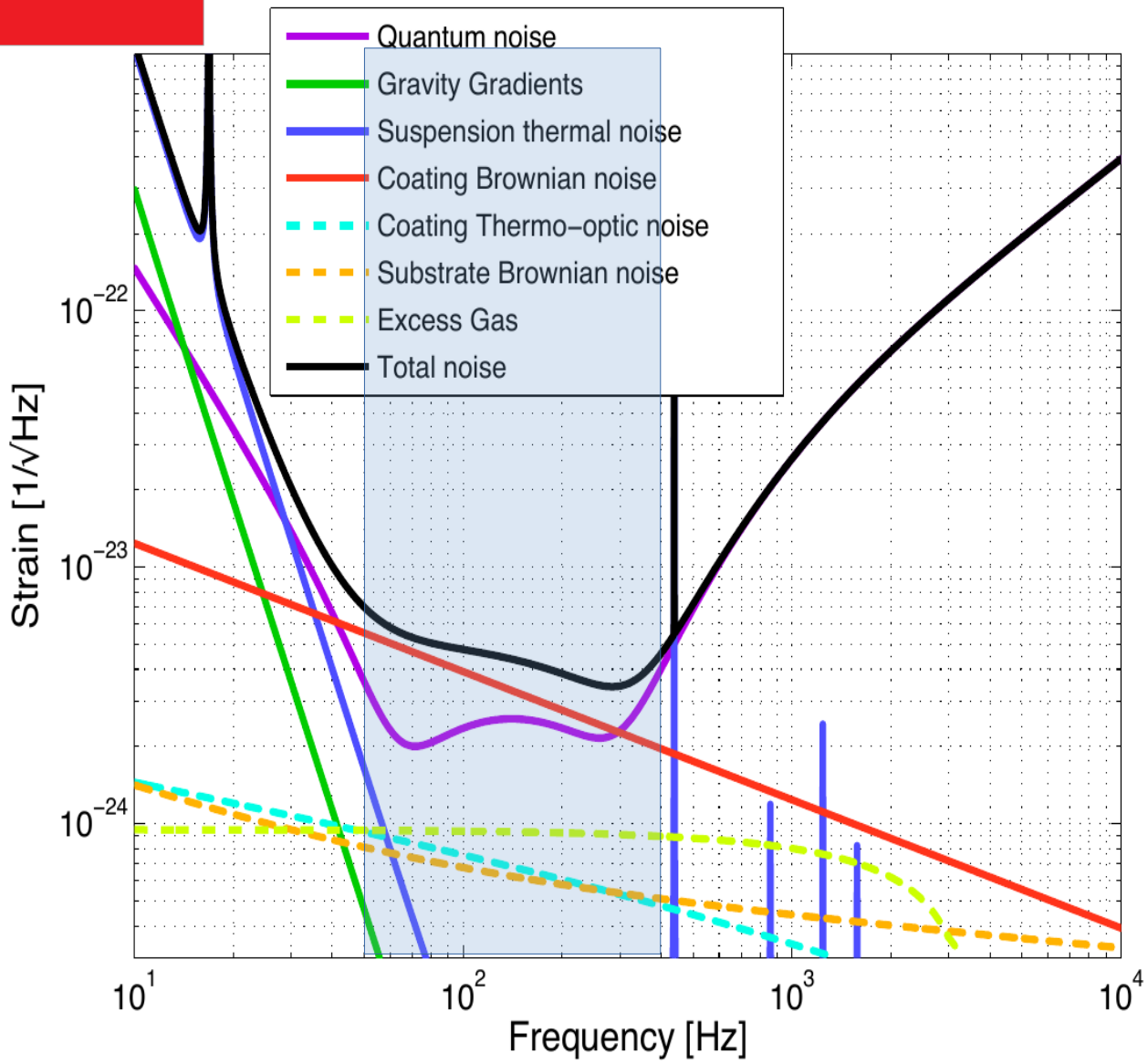
Advanced Virgo Configuration

Mid Frequency Range

Coating Thermal Noise

Reducing thermal noise:

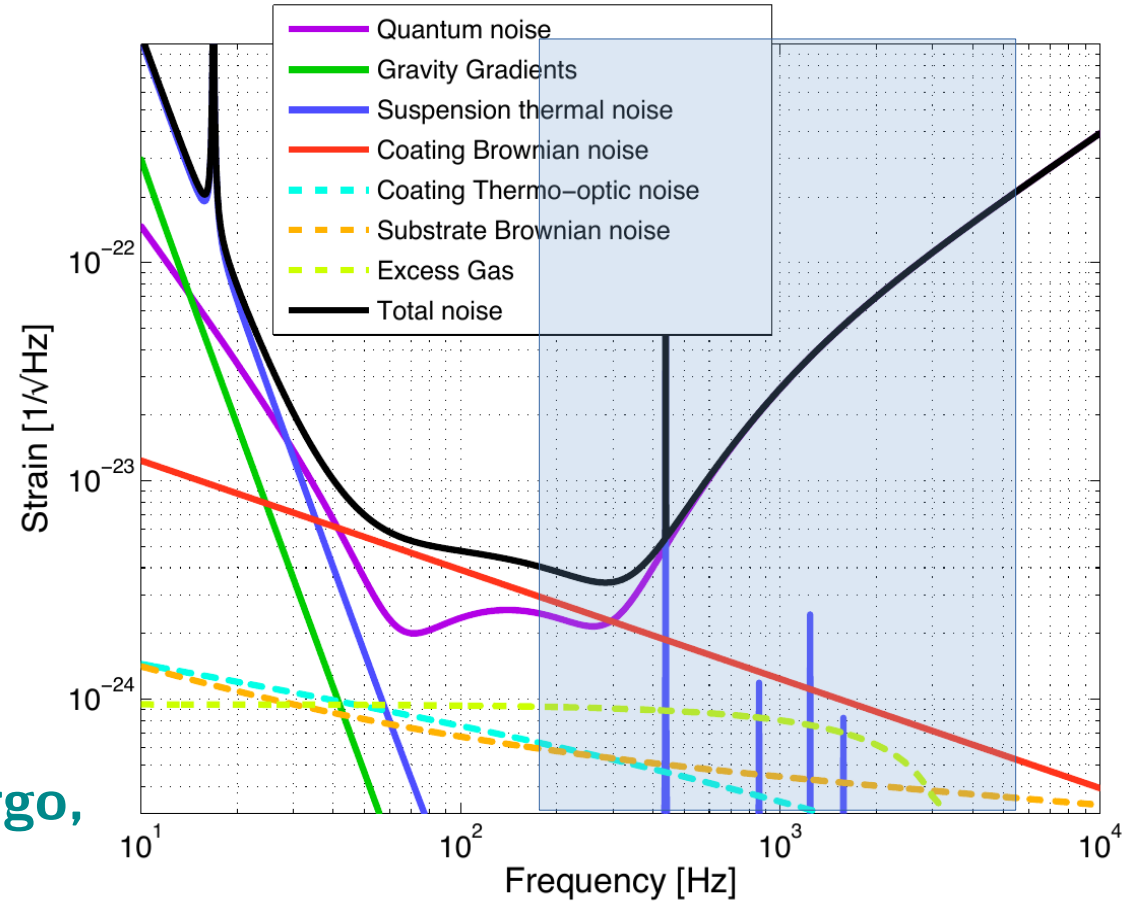
- **increased beam size @ input TM (2.5 x larger)**
- Improved coatings for lower losses (7 x better)



Advanced Virgo Configuration

High Frequency Range

Quantum Noise



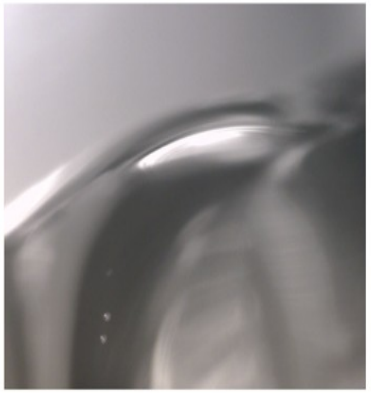
Reducing quantum noise:

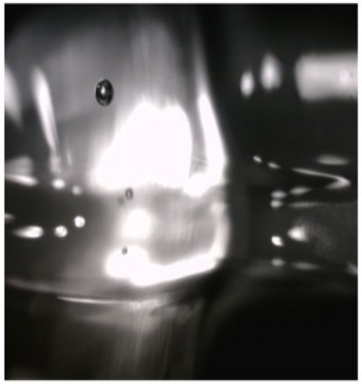
- **Increased finesse of arm cavities (9x larger than in Virgo, 3x larger than Virgo+)**
- **High power laser**
- **Squeezing technology**

STATUS VS O2

Main TRUBBLE before O2:

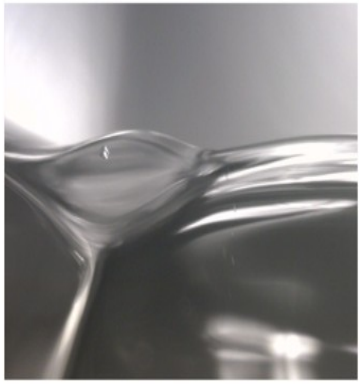
Monolithic fused silica suspension *breaking failures*





AdV quasi-monolithic suspensions, same successful design adopted since 2009, broke several times and a **deep investigation was needed**

Tests conducted through an intensive collaborative effort conducted also outside Virgo collaboration (e.g. Glasgow, ext. companies and research institution)



Evidences of isolated bubbles in 3/8 cases

- Small bubbles in SiO2 (seemed the most promising)
- Quality of welding
- Mechanical impacts inside the payload structure
- Stress FEA studies
- Cleanliness and assembly procedures
- .....
- Existence of a radioactivity near the payload (the most exotic)

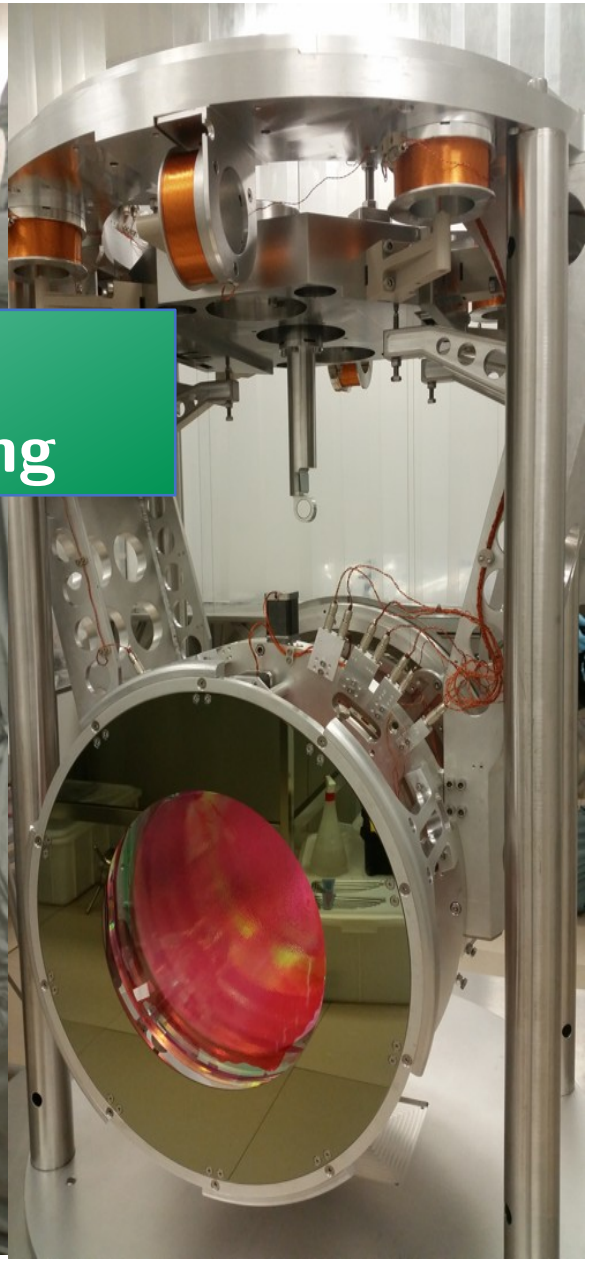
Breakdown causes finally identified as arising from vacuum/venting inlets (valves) at least in 7/8 cases

Backup solution to join O2: *readapting payload to steel wires*

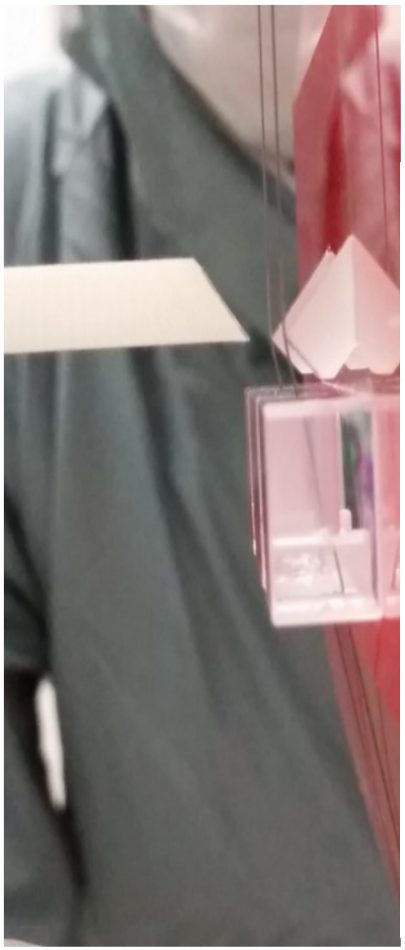
Backup solution to join O2

Back to the past

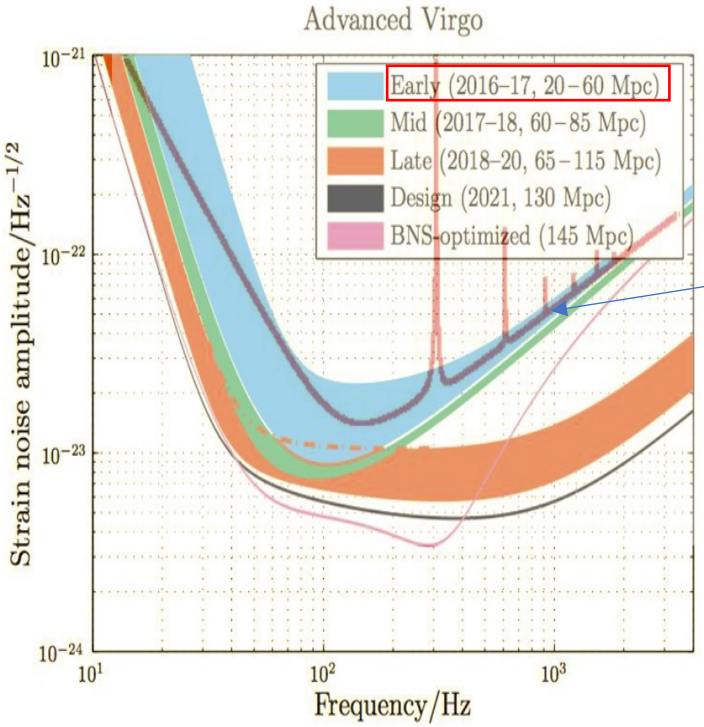
before V+, 2011,
***just to allow* AdV commissioning**



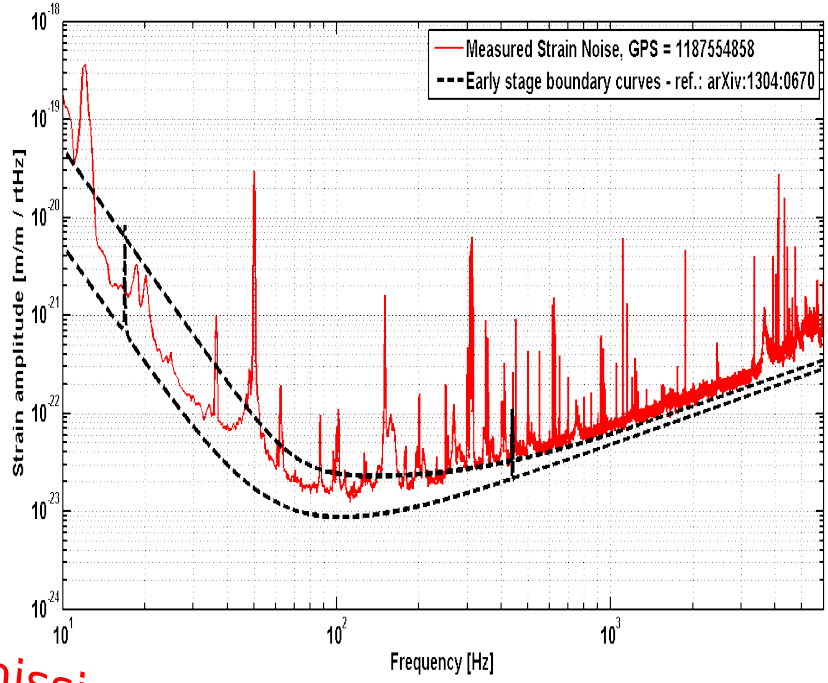
Backup solution to join O2



Monolithic suspensions: *Sensitivity VS steel-wire backup*



Sensitivity with steel wires
still compatible
with the goal for the early phase



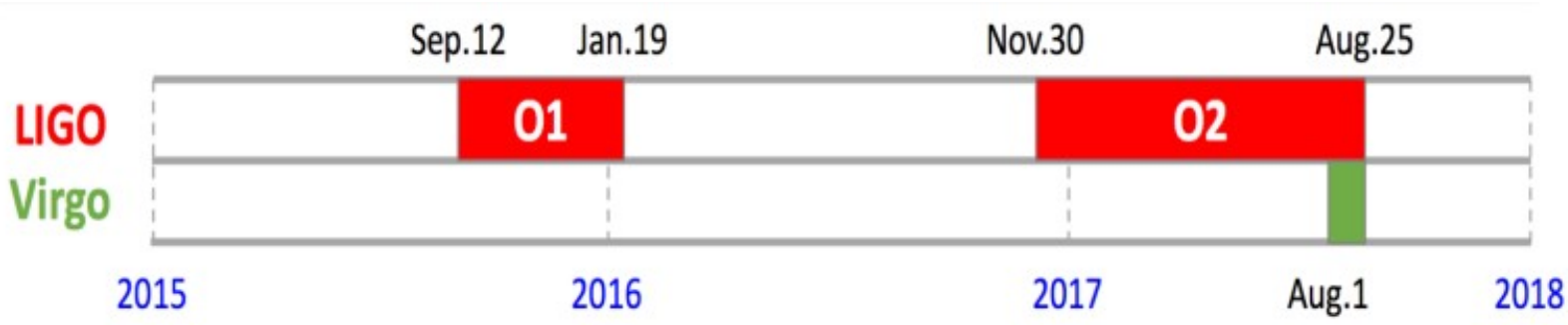
Steel (f=10^{-3})
Horizon NS-NS - 45 Mpc
Horizon BH-BH - 202 Mpc

Through a very fast commissioning rush

Monolithic
Horizon NS-NS - 101 Mpc
Horizon BH-BH - 985 Mpc

BNS range ~ 28 Mpc:
ready to join O2!

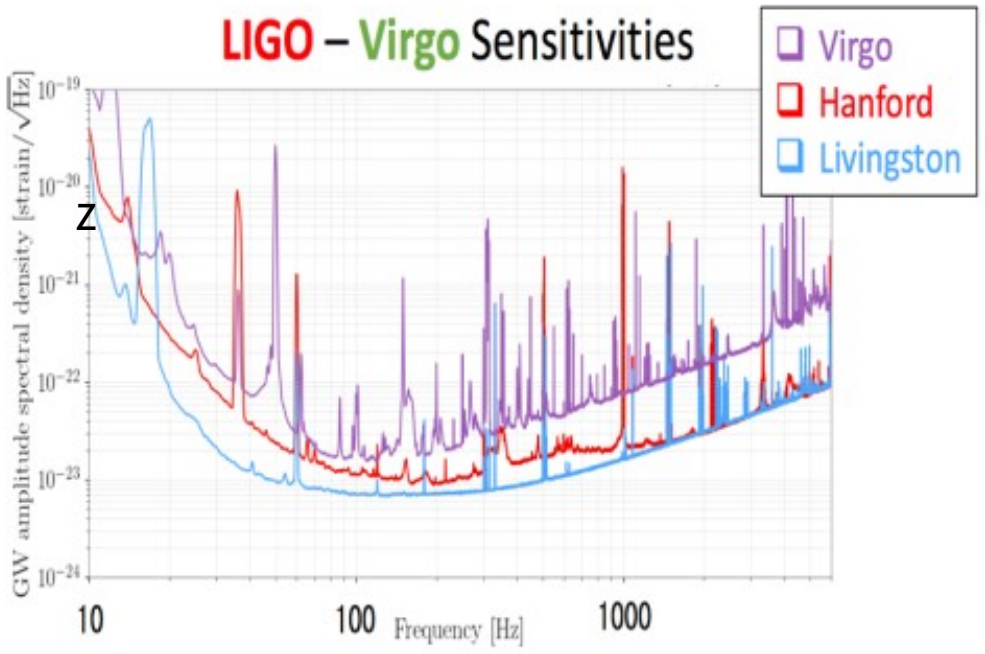
O2 Summury: the exciting 16 days!!!



- O1 ~49 *days* of coincident LIGO data
- O2 ~120 *days* of coincident LIGO data
  ~16 *days* of coincidence with Virgo data
  10 GW alerts for EM follow-up

Averaged distances to which Binary Neutron Star could be detected

VIRGO : 26 Mpc
HANFORD : 55 Mpc
LIVINGSTON : 100 Mpc

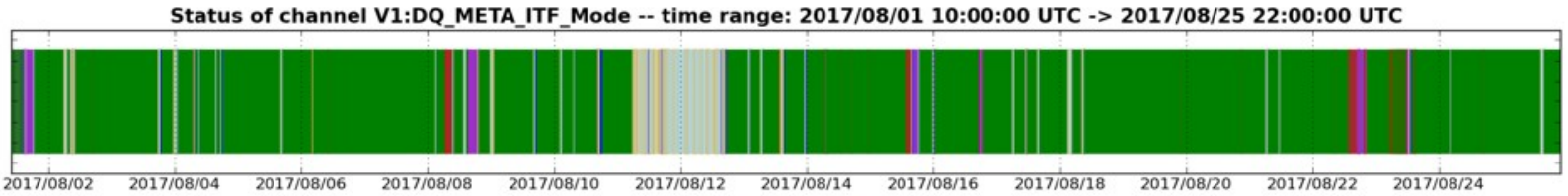


❑ observations 2015-17 vs 2010:

averaged observable volume of Universe : **~100x** gain for **BBH** like GW150914
~30x gain for **BNS** coalescence events

Two well known events detected through LIGO-Virgo network

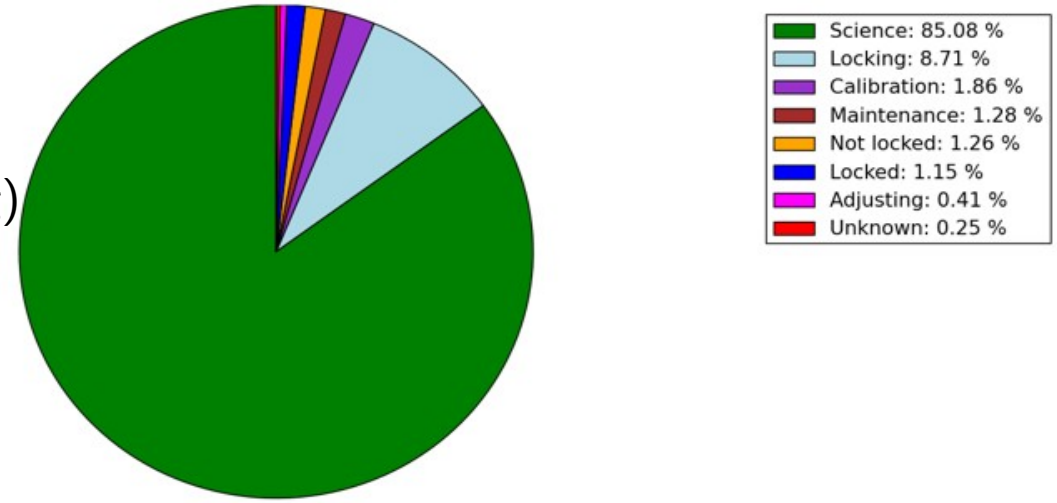
O2 summury



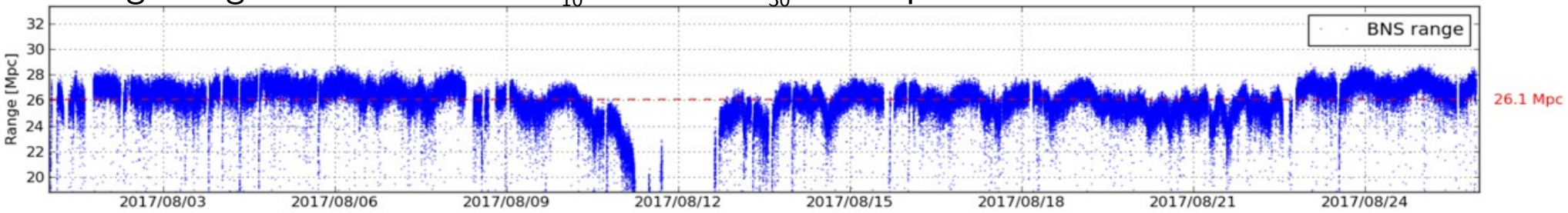
Quiet weather conditions (summer)

Good duty cycle

(85.5% in spite of some technical bug)



Average ranges: **BNS 26** - BBH_{10} 134 - BBH_{30} 314 Mpc



Highest BNS range: 28.2 Mpc

Short duration

Glitchness to be reduced

Automatic Alignment accuracy to be improved

Towards O3

Upgrades after O2

Target sensitivity for O3:
60 Mpc NSNS std candle

Strategy:
→ Reserve commissioning time
→ Limit the number of upgrades

Upgrades before O3

priority

I. **Monolithic suspensions restoration**

During O2 (GW detection in August 2018) Virgo adopted
steel wires in the last stage suspension, as a backup solution after the monolithic suspension breakdown

II. **Vacuum system modifications**

Breakdown causes finally identified as arising from vacuum/venting inlets at least in 7/8 cases

III. **LASER amplifier integration**

IV. **Squeezing (AEI)**

V. **Integration of seismic sensors deployed around ETM for NN studies (monitor)**

Upgrades after O3: High Power Laser operation,
Squeezing (2° phase)... Signal recycling

Monolithic supensions re-installation

Main benefit:
monolithic suspension
as removing the steel wire thermal noise
provides a *20 Mpc range increase*

Done in 14 weeks

including recovery of four unforeseen issues (2 weeks)

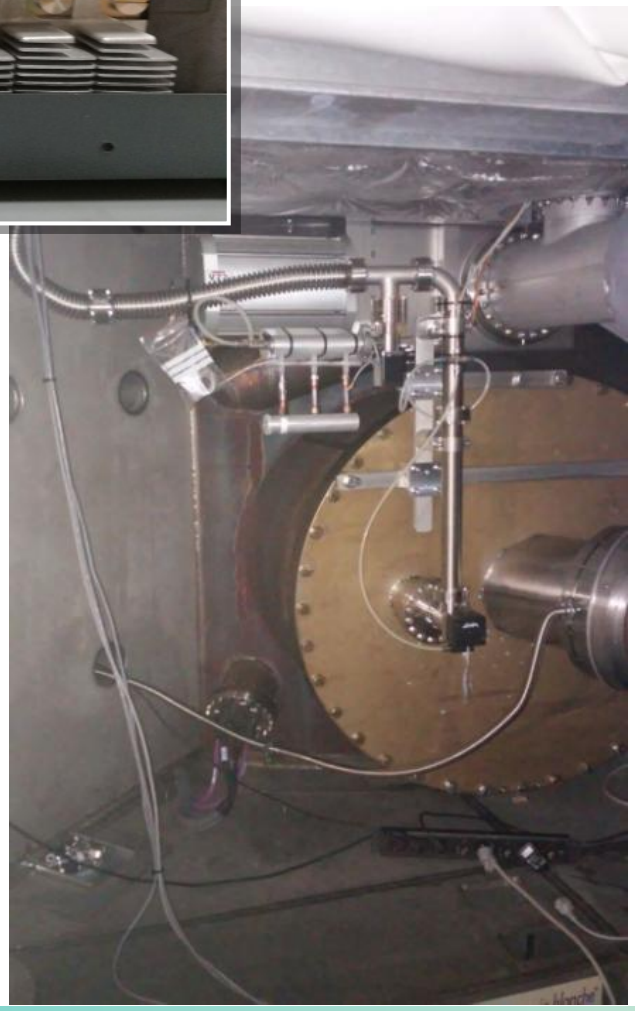
09.01.2018
integration NORTH INPUT

Vacuum System modification

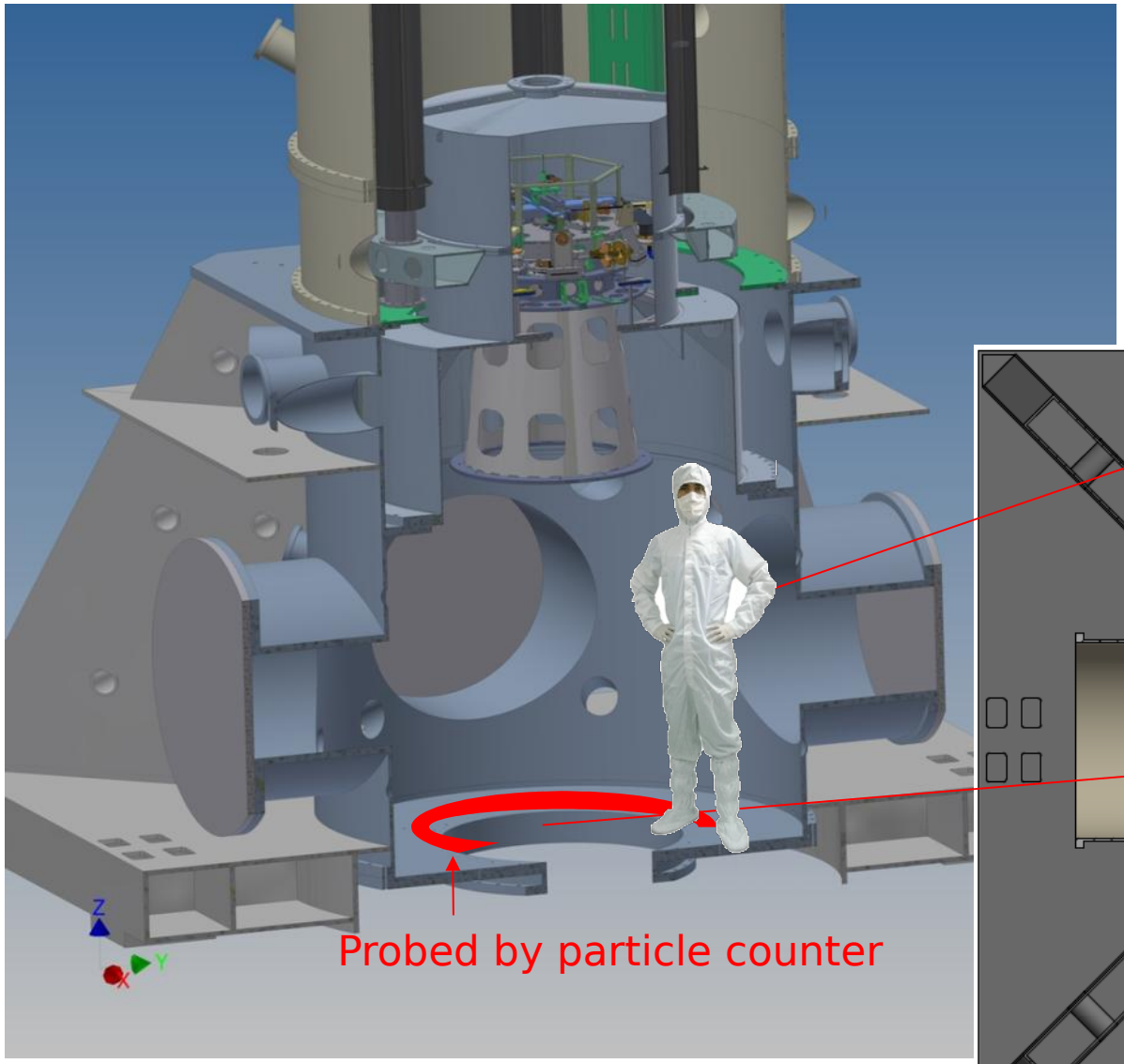
To prevent monilithic suspensions brakdown

Avoid dust generation and injection into the vacuum system

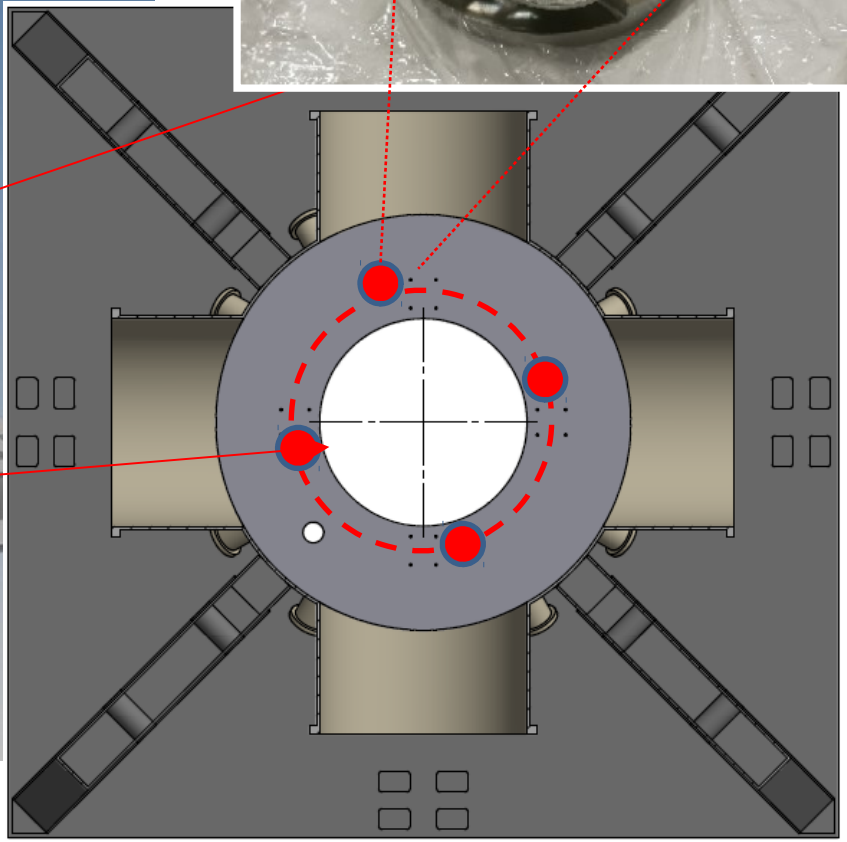
- Different pumps
- Different venting circuit
- Filters, shields, ...



Extraordinary cleaning and dust survey



Silicon witness wafer placement

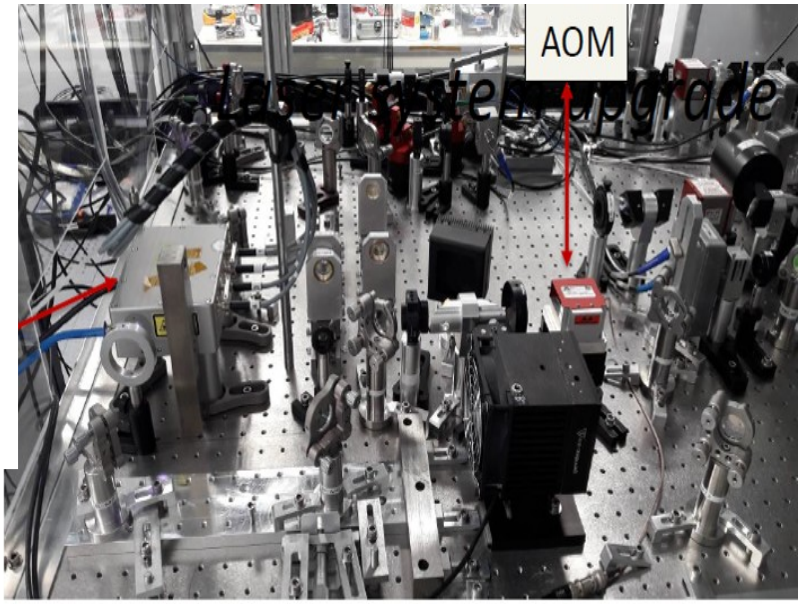


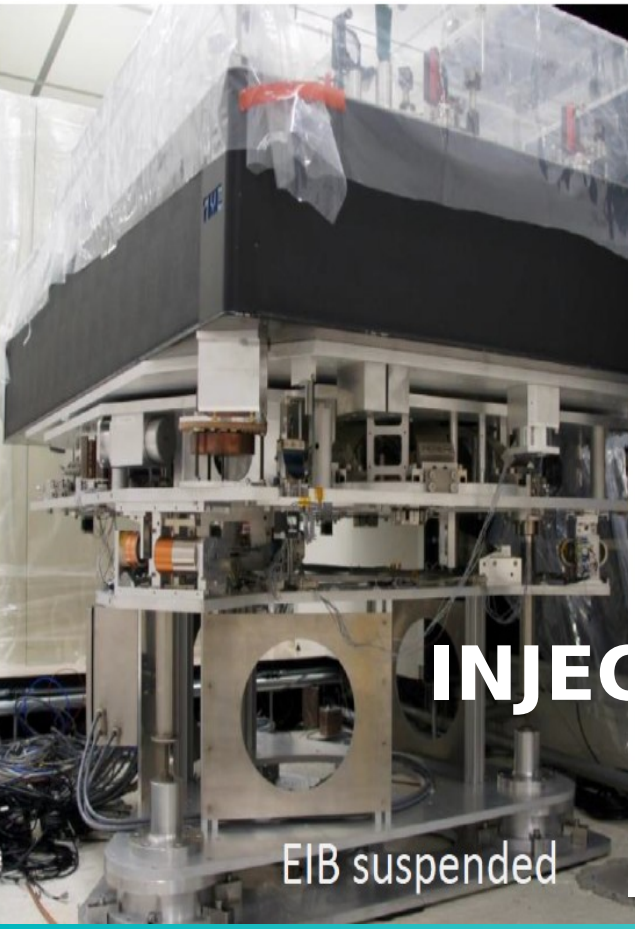
High Power LASER

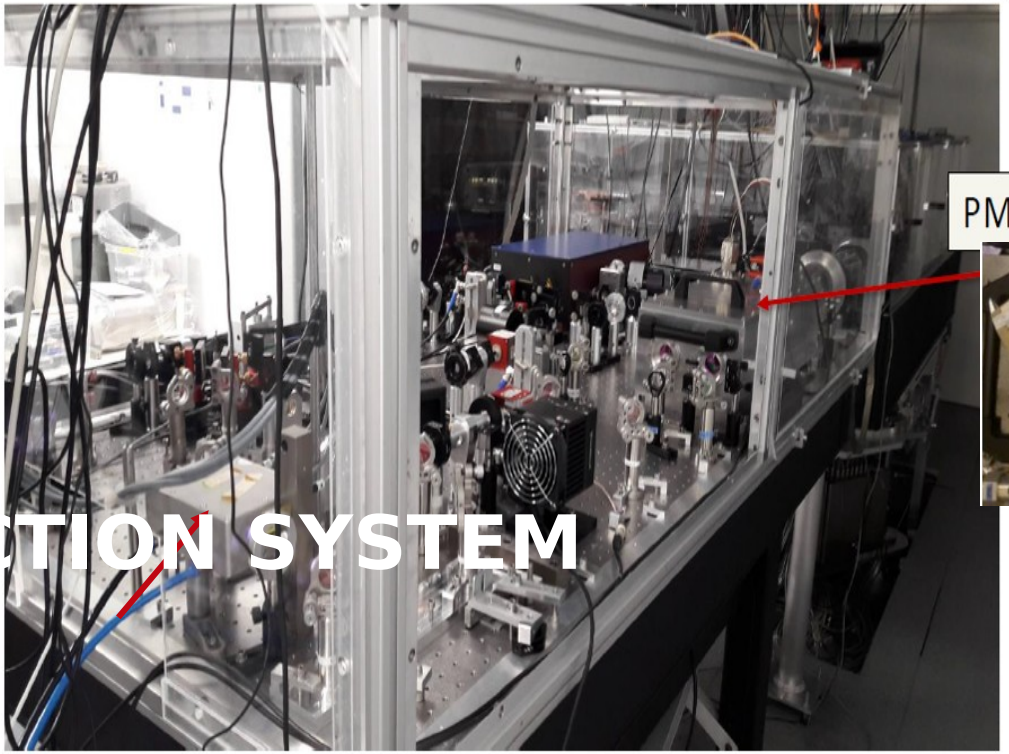
70 W amplifier *replaced by* a 100 W

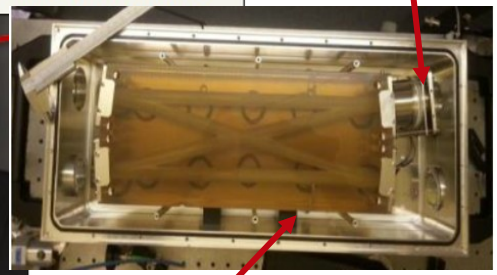
Max input power in the ITF: around 50 W
100 W fiber laser tests ongoing at Nice

New pre-mode cleaner
External Injection Bench "suspended"









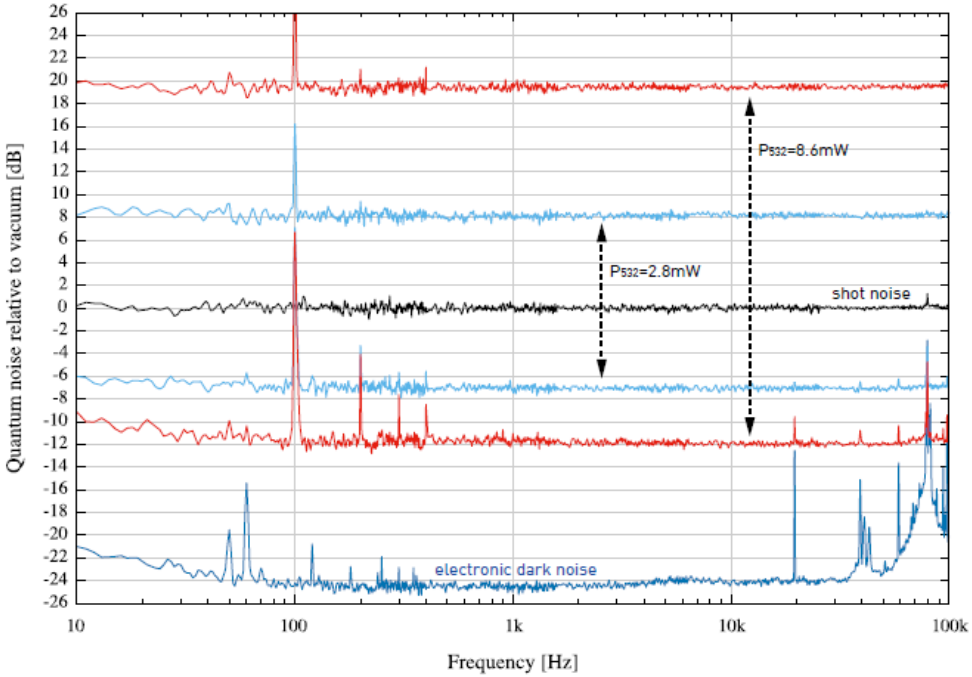
INJECTION SYSTEM

Frequency Independent Squeezing

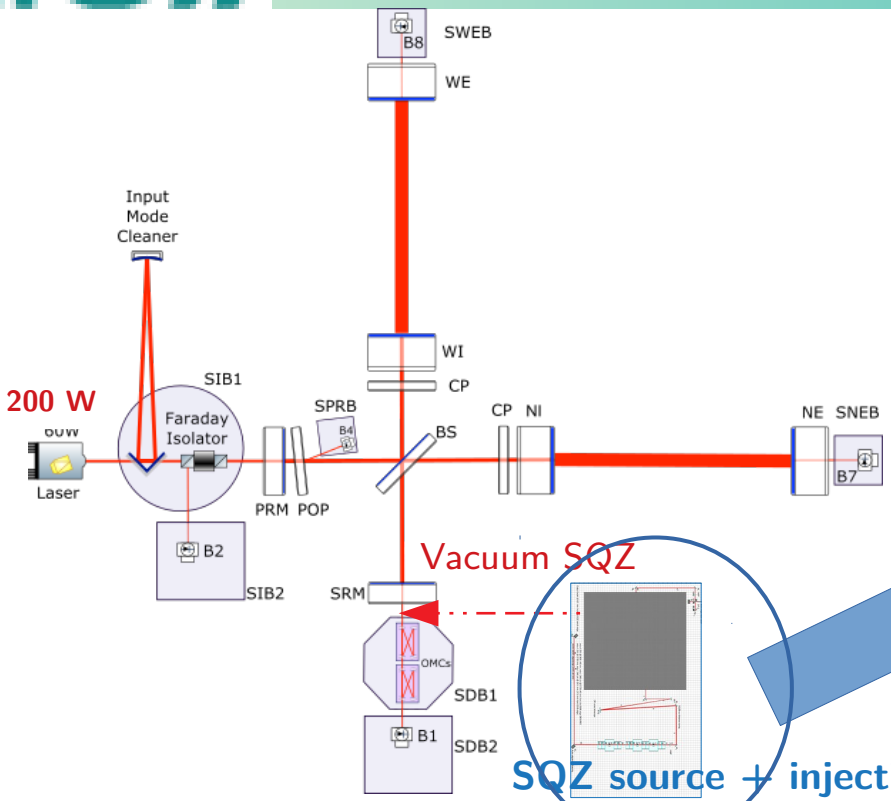
Max Planck Institute AEI collaboration
to integrate **plug&play squeezer bench,**
presently under commissioning

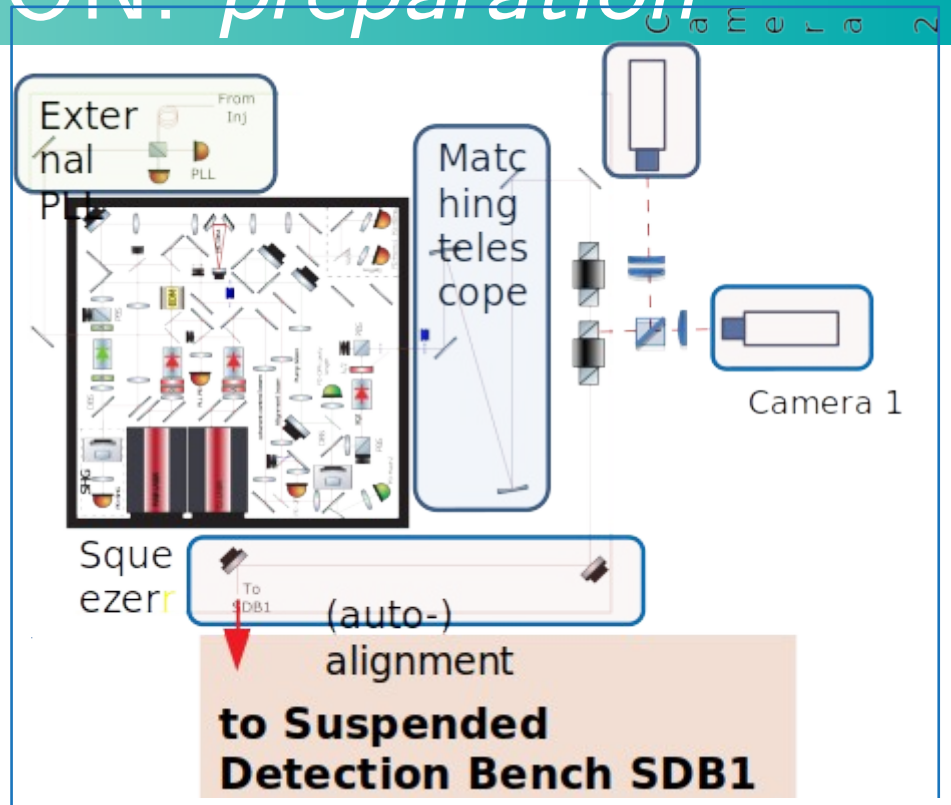
Two identical boxes have been developed, the second one remains in Hannover for debugging

Up to **12 dB** of squeezing degree demonstrated in the **audio band**

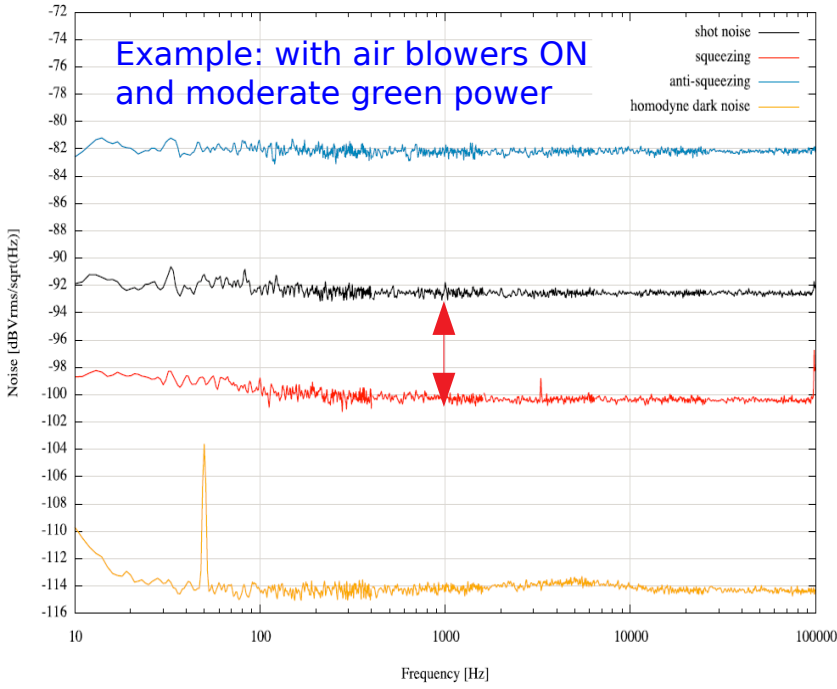


FI SQZ INJECTION: *preparation*

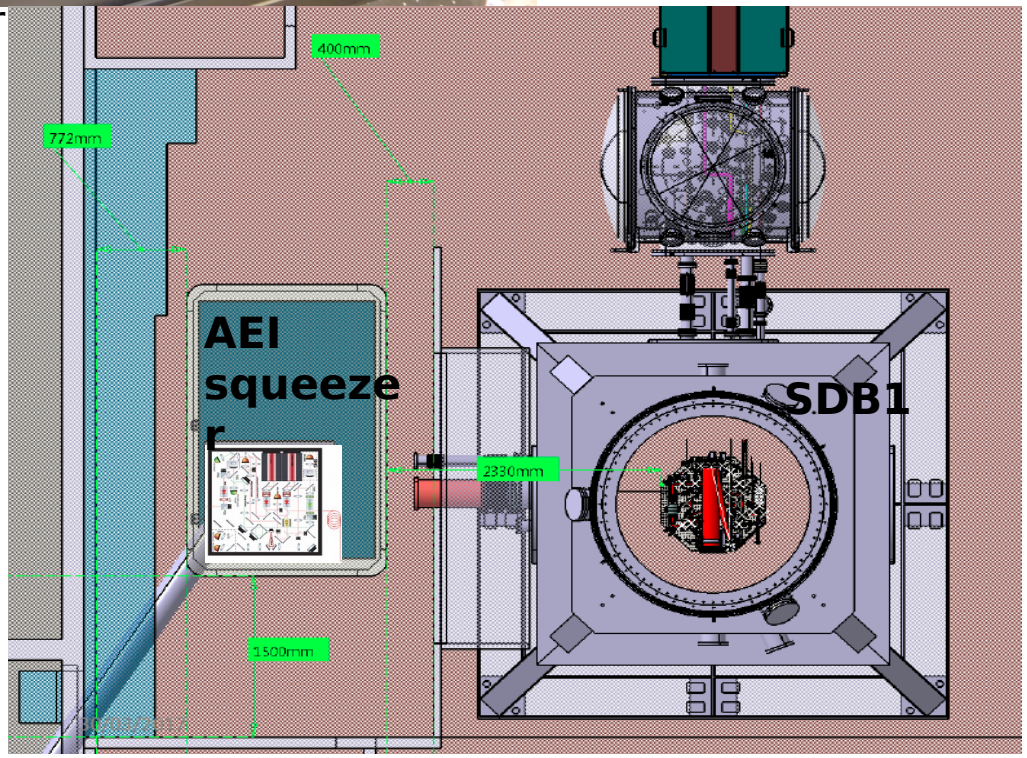




Hannover results reproduced in Cascina

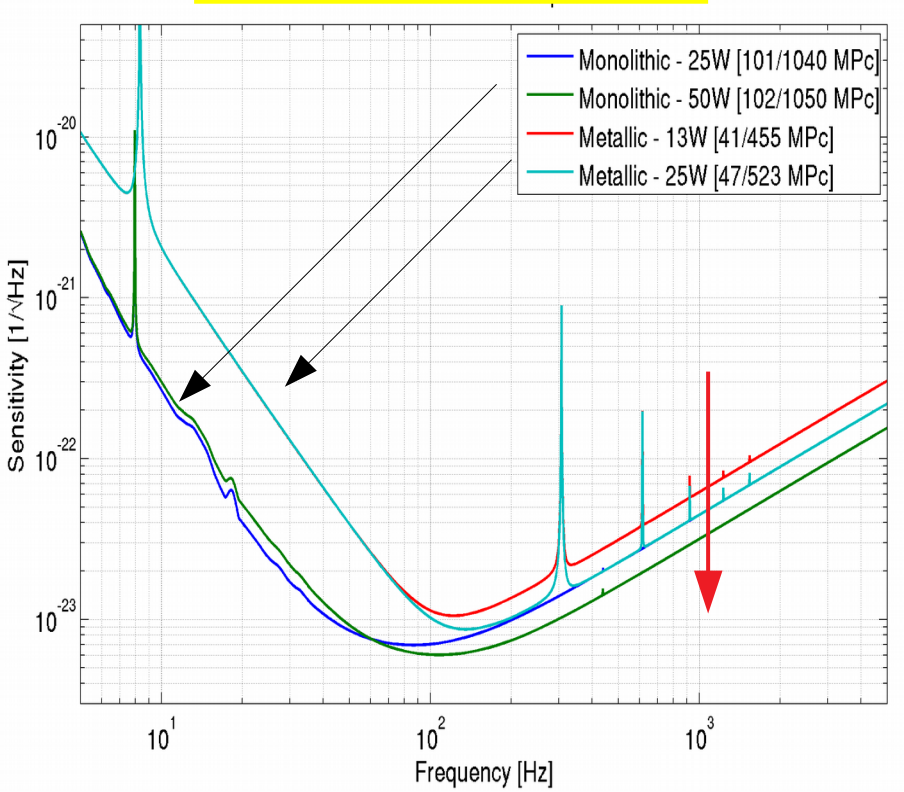


The AEI squeezer in AdV

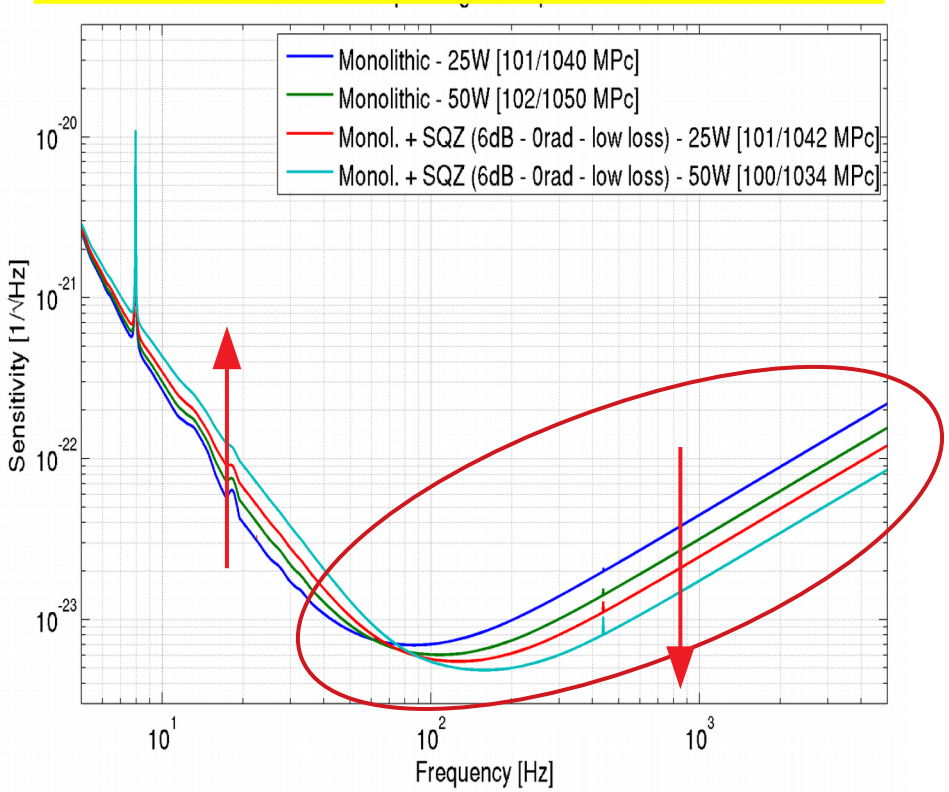


HP laser + SQZ effect

Laser Power



Laser Power + FI SQZ



SQZ => increases the sensitivity in HF range without increase further the laser power

Limitation: increase of RP noise at LF → FDSQZ needed (after O3)

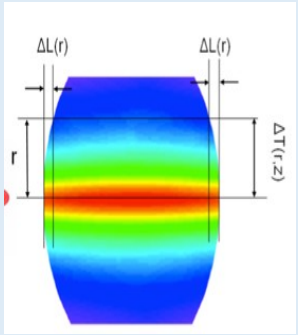
TCS, AdV Thermal Compensation System

Will be in use during O3 !

✓ High circulating power changes the ITF nominal optical configuration:

✓ Thermal lensing

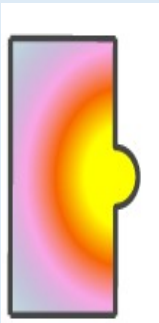
$$\Delta OPL_T = \frac{dn}{dT}\int_S \Delta T ds$$



OPL distorsions due to dependence of refractive index from temperature variation

✓ Thermo-elastic effect

$$\Delta u \approx \alpha \int_S \Delta T ds$$



Change of RoC of mirrors due to the absorption of laser power

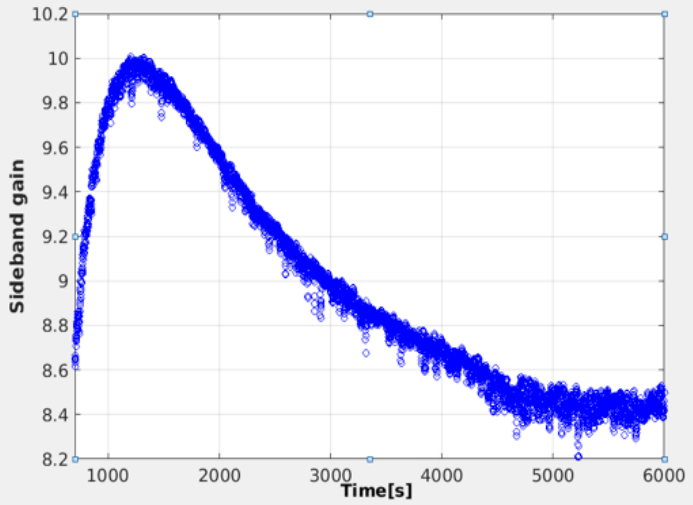
€

✓ ITF control signals degradates

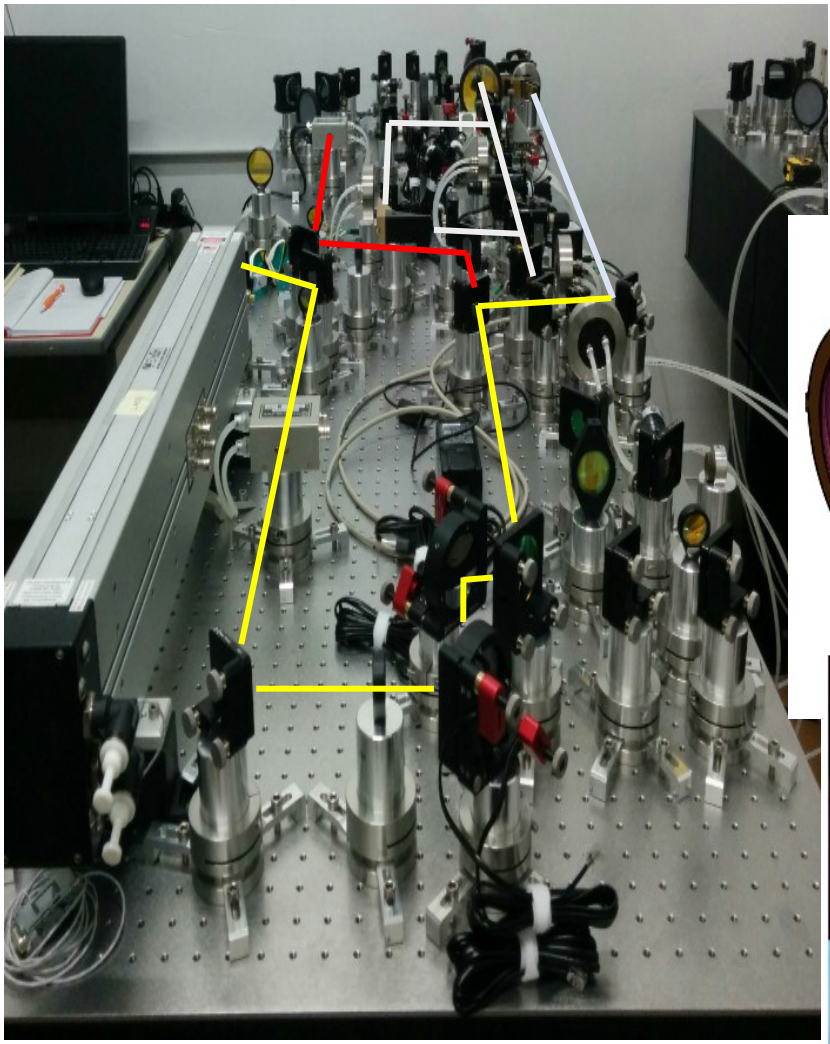
✓ Sensitivity decreases

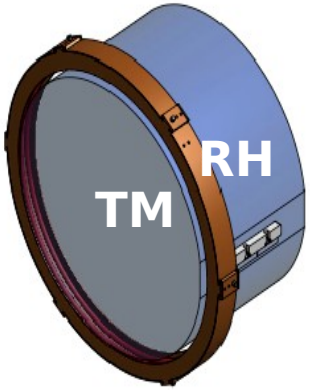
✓ **TCS thermally acts on the ITF optics, restoring the nominal operating point**

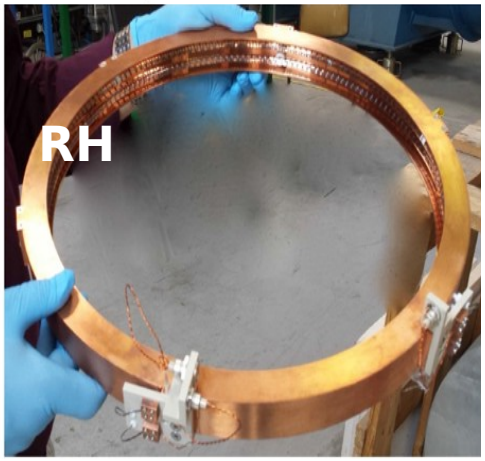
Typical behavior of the ITF control sidebands due to the effect of thermal lensing

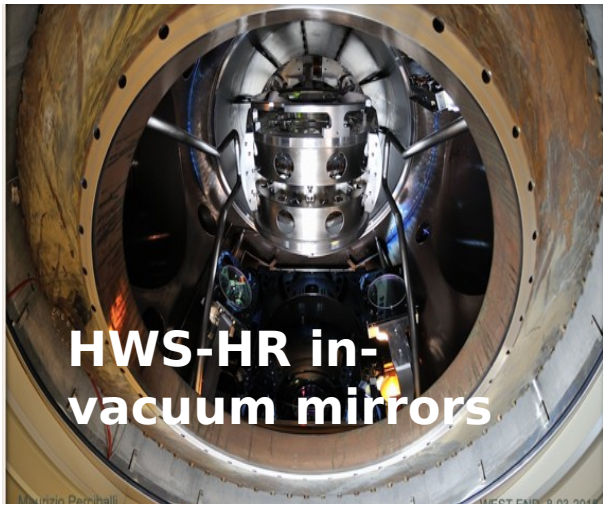


TCS being commissioned to be ready for O3

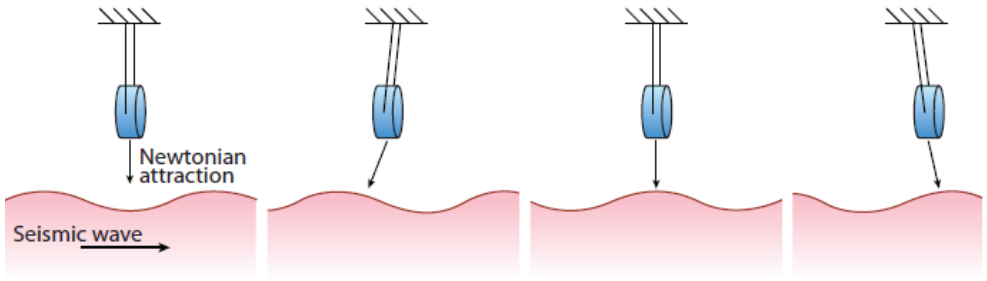








Newtonian Noise: preparing noise substraction in O4

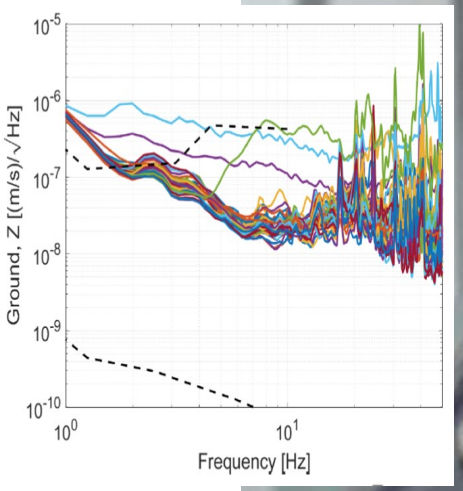


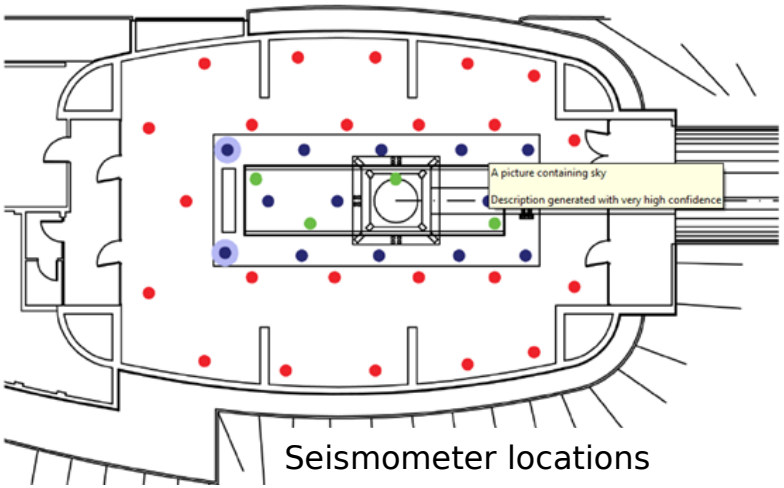
Test sensors array installation

(about 50 sensors foreseen in each terminal building)

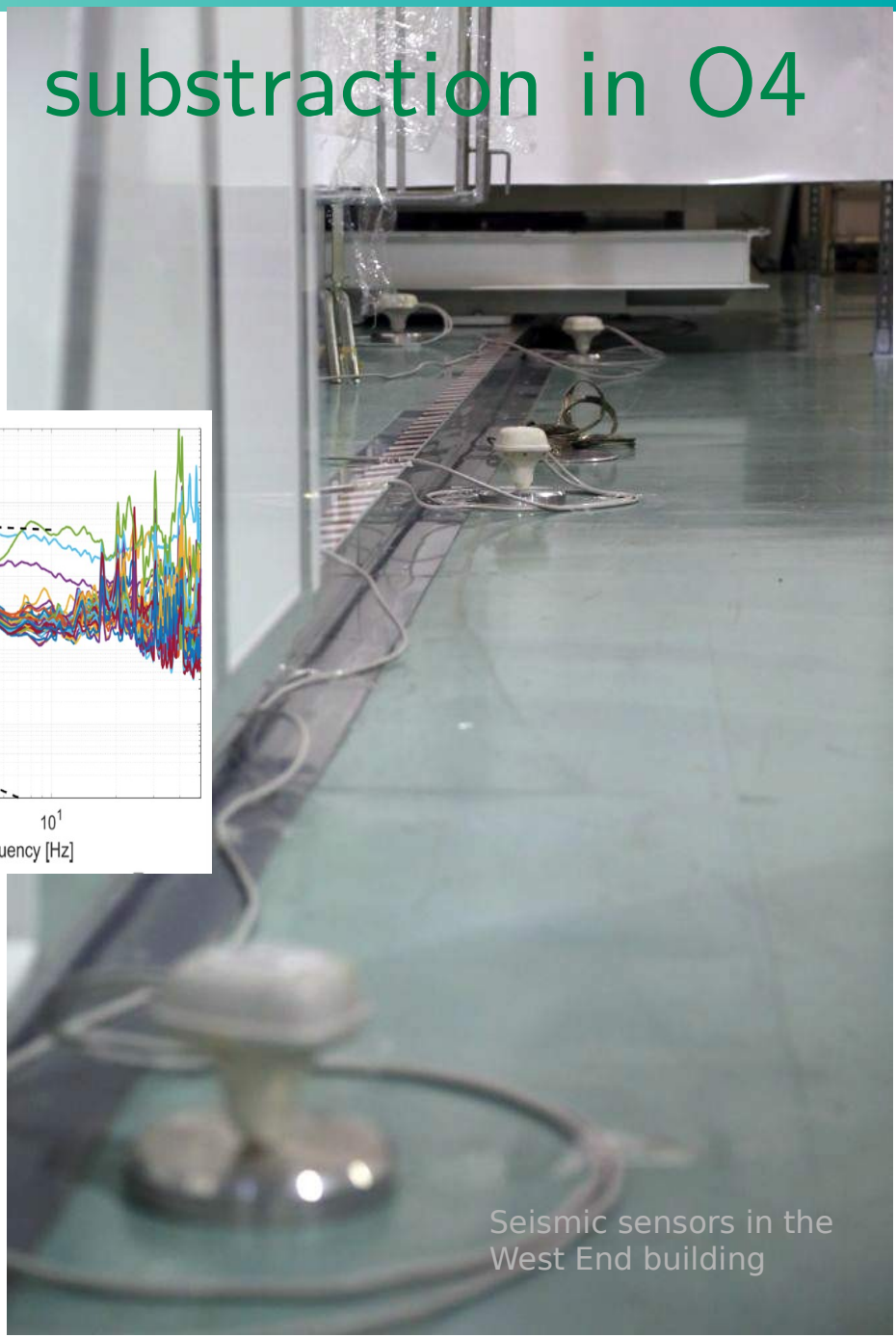
→ 2-weeks recording of seismic noise

→ Seismometer data being analyzed





Seismometer locations



Seismic sensors in the West End building

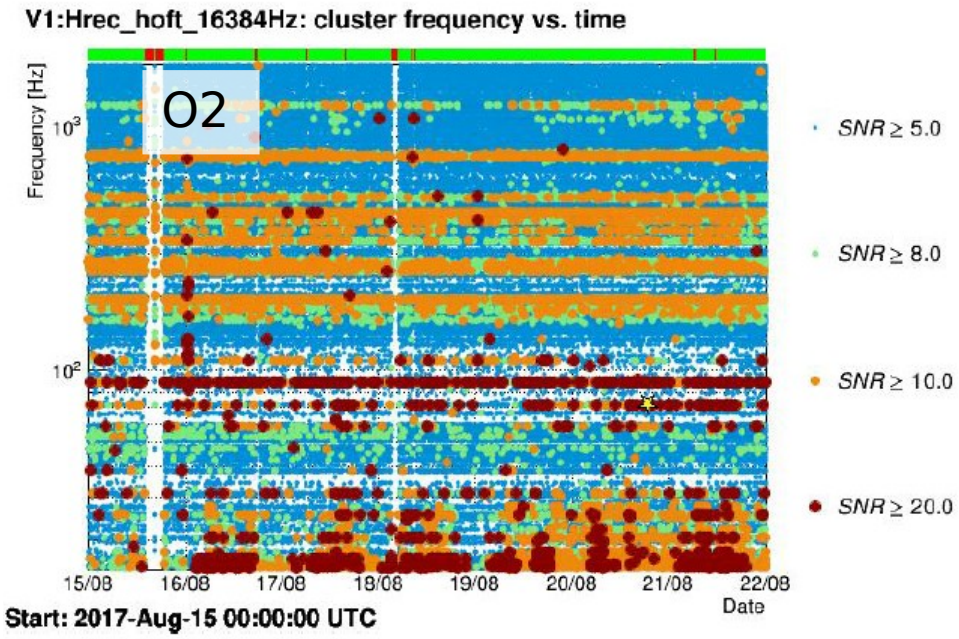
Present status of the machine

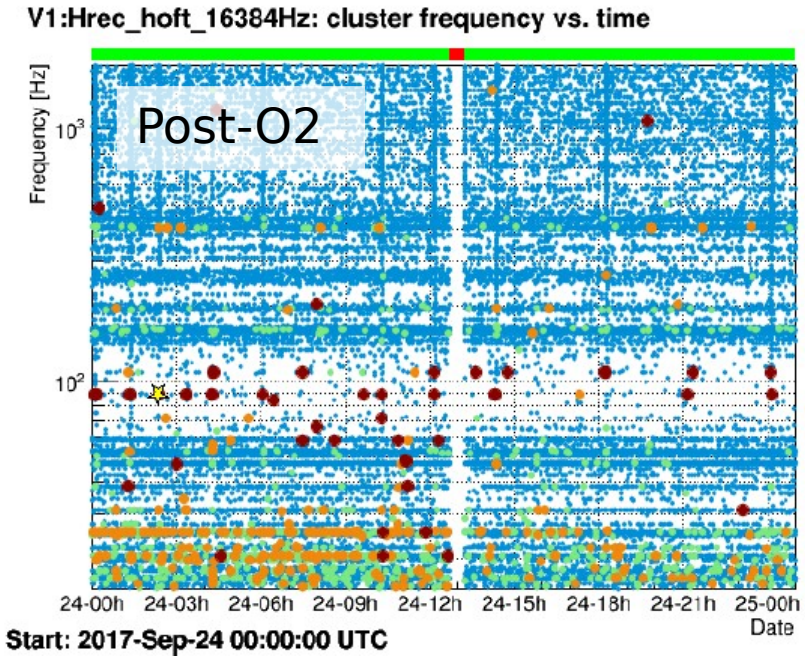
Sensitivity

Improvement at low frequencies
Still recovering from upgrades at high frequencies

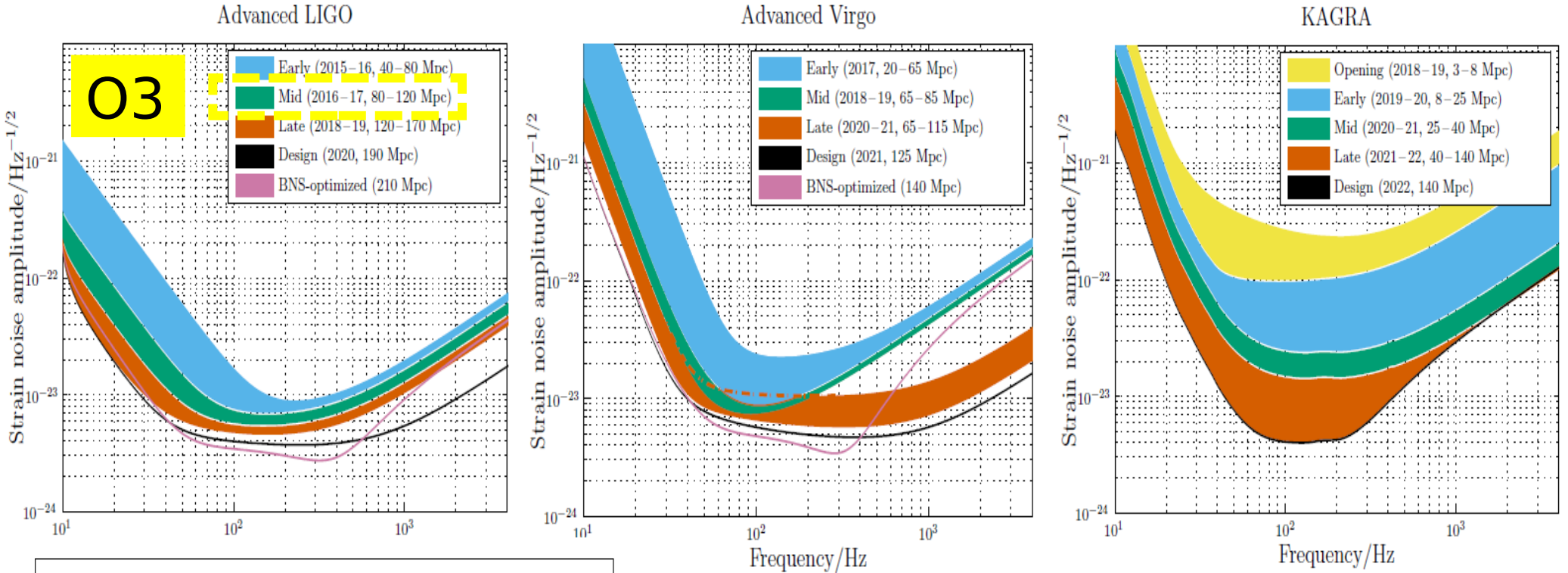
Glitches

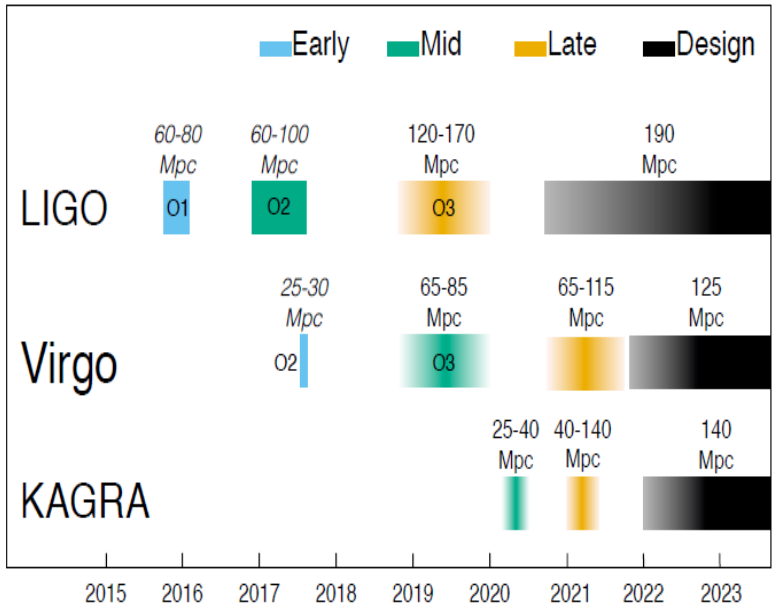
Much reduced glitch rate after O2 *(autoalignment, Global Inverted Pendulum Control...)*





Future prespective





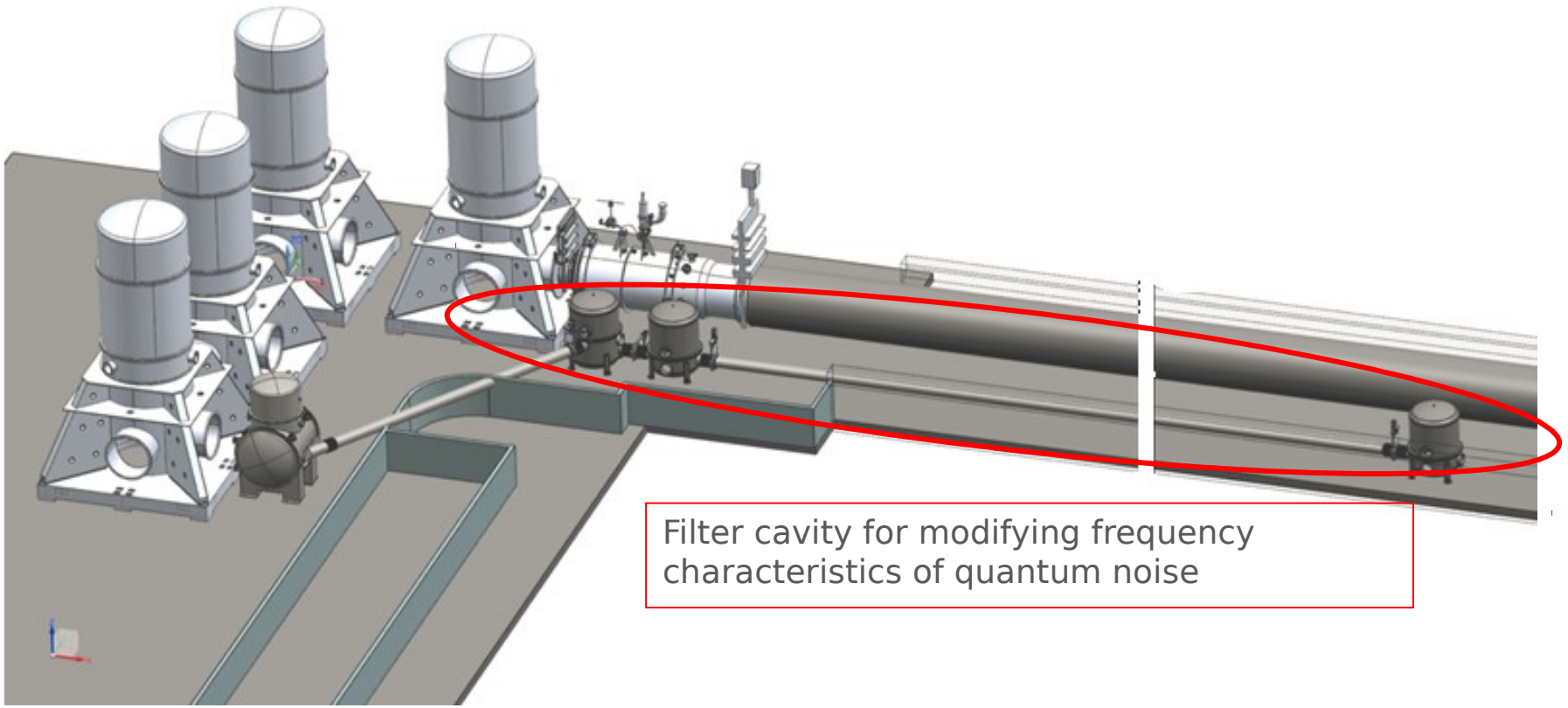
- O3 is a very exciting scenario (including KAGRA, a **seed of 3G detector)**
- What can we do after AdV to exploiting at the best the infrastructure ?
- **AdV+ vision document** proposed to Virgo Council: a two-phasee approach, 6-year programme

Newtonian Noise subtraction

Test measurements ongoing

Frequency-Dependent Squeezing

Further optimize quantum noise for improvement over the whole frequency range



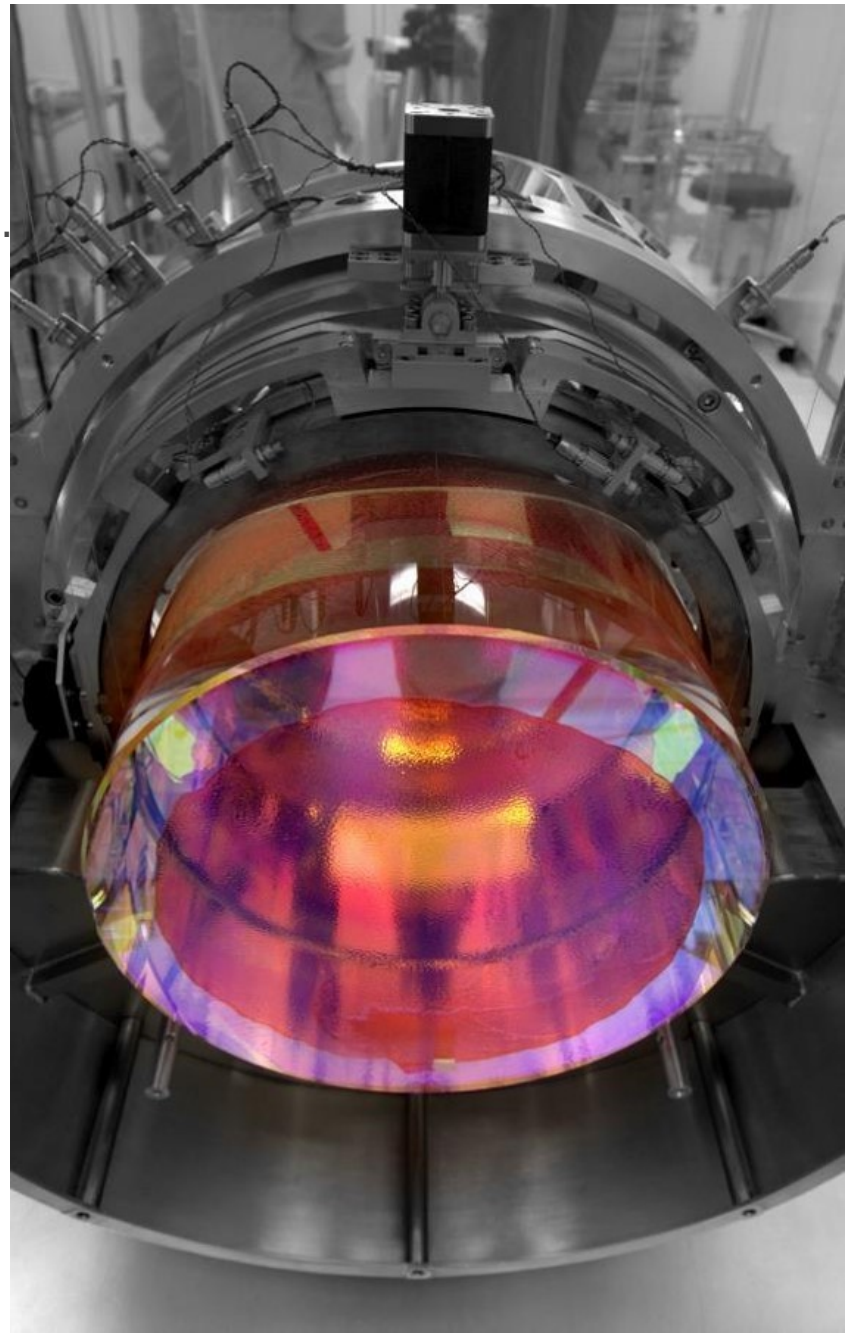
Increased mirror size

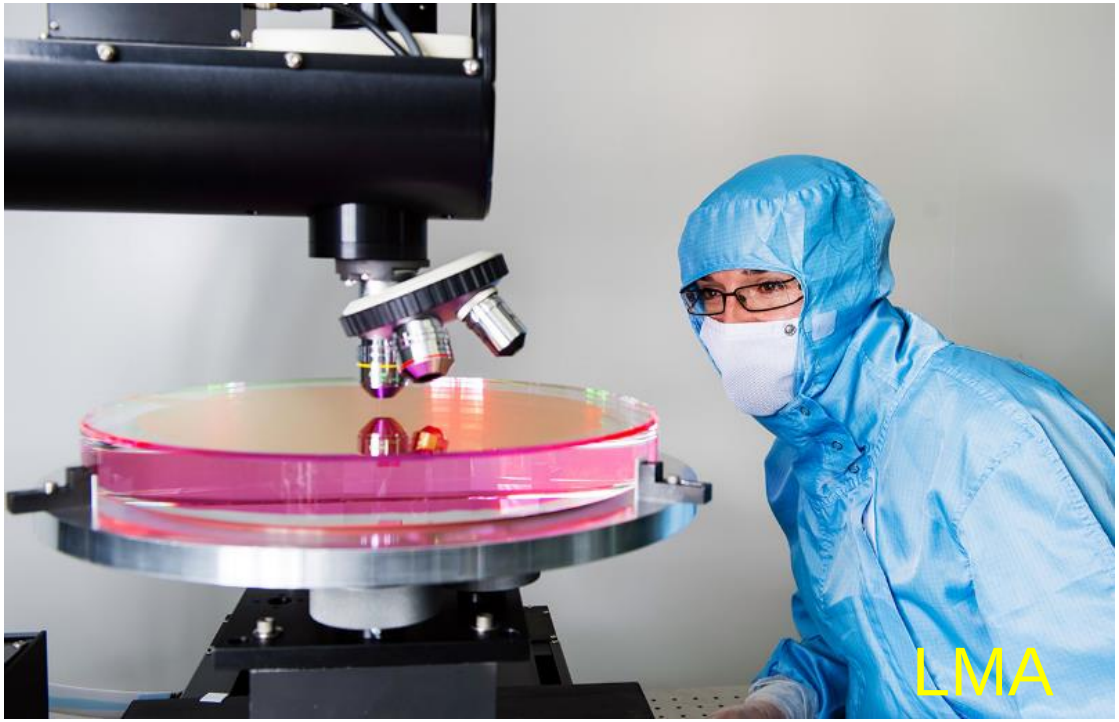
Better averaging over thermal fluctuations

Challenge for fabrication, handling, suspensions, ..

Better coatings

Big R&D effort needed





Conclusions

- Virgo upgrades towards O3 done

  - Monolithic suspensions
  - Laser power increased
  - Frequency independent squeezing

- O2 sensitivity just recovered

- Commissioning run with higher sensitivity in fall 2018

- Target 60 Mpc (BNS) achievable with the HP laser installed

- One-year-long organisational and data storage (uncommented here), seriously considered

THANK YOU VERY MUCH!