European Commission

INFN Istituto Nazionale di Fisica Nucleare

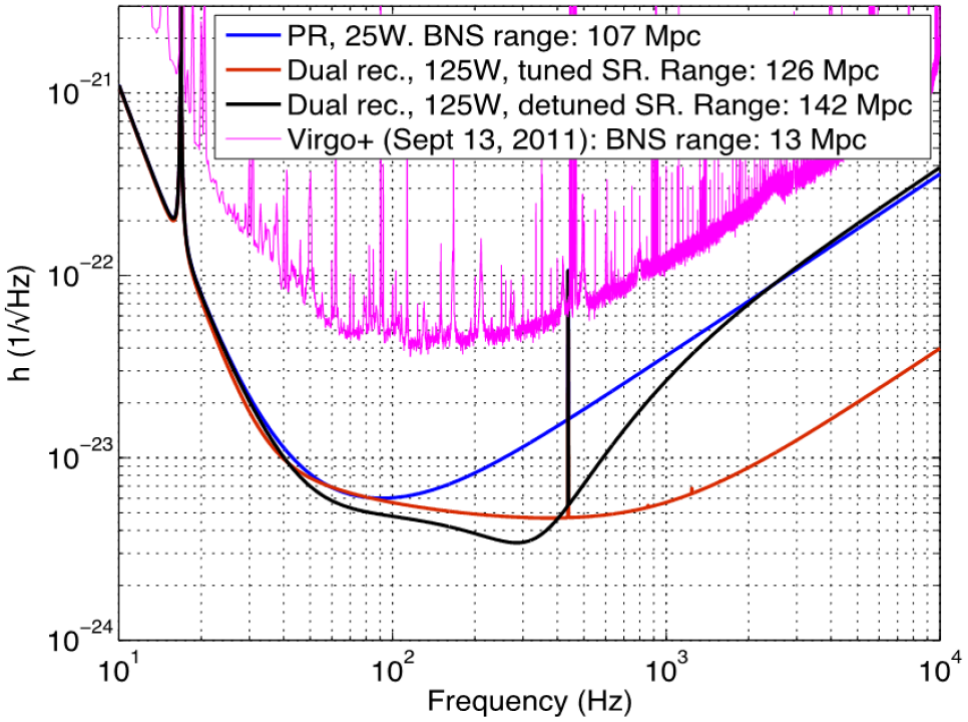
Status of Virgo, towards observation run O3

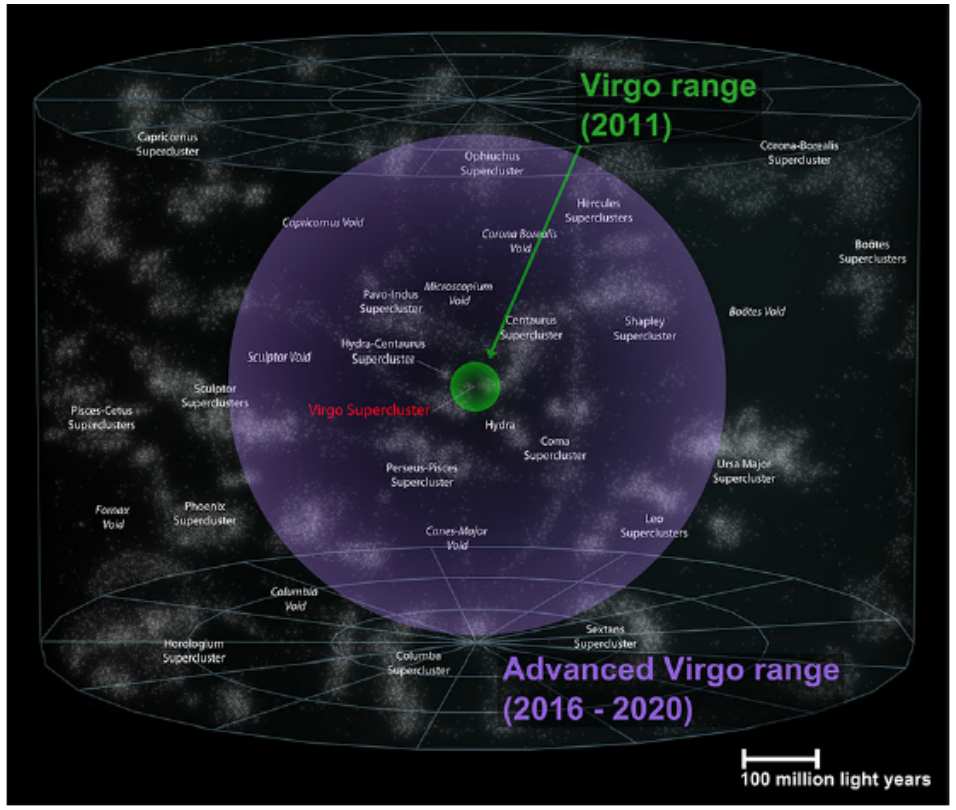
E. Majorana

NEWS workshop, Pisa, 14 Mar 2018

Science case

10 x sensitivity improvement over 1st generation detectors

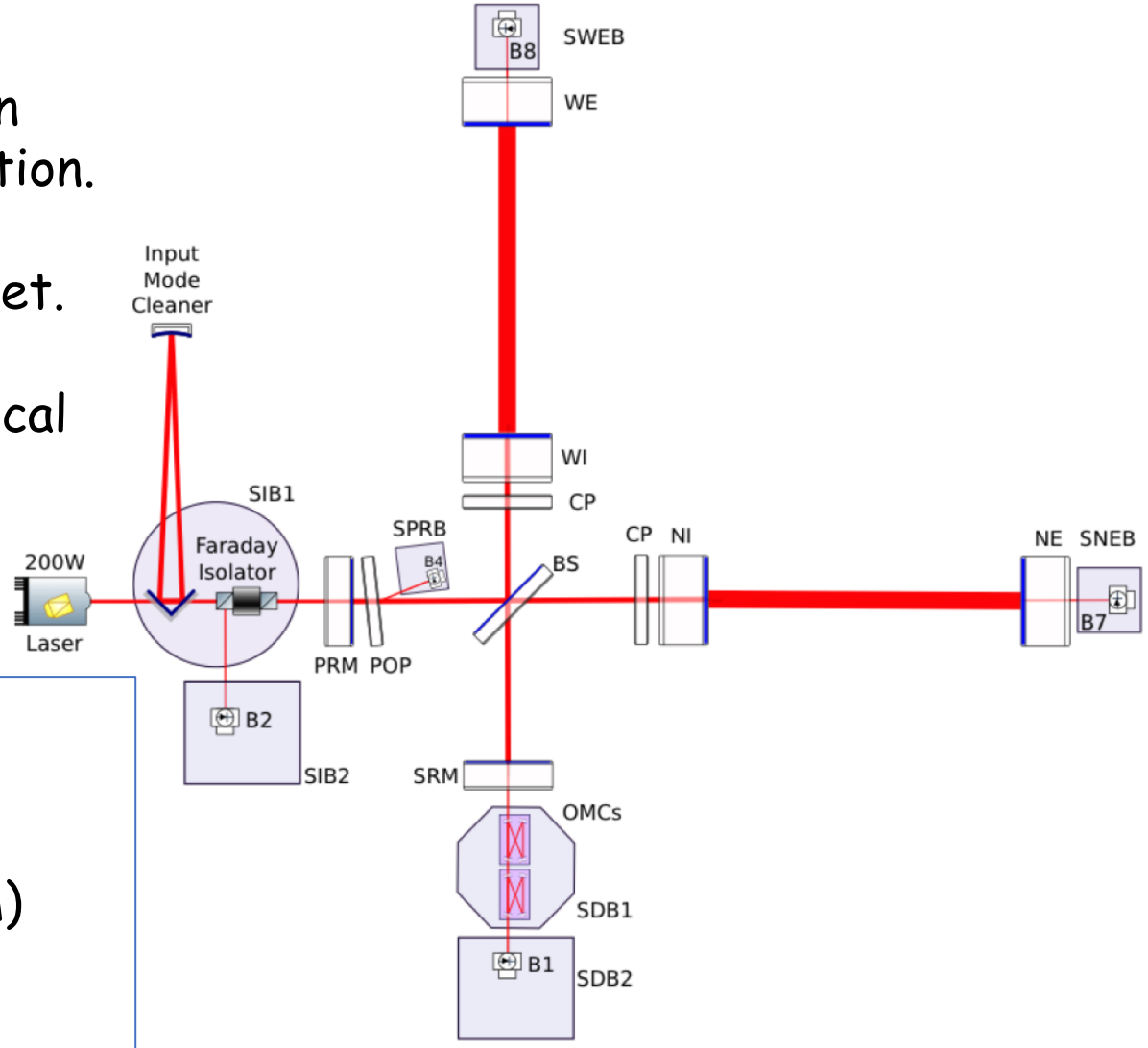




1000 x increase of observation volume

Advanced Virgo layout VS O2

- Virgo collaboration rushed to join observational run O2, August 2017, adopting a preliminary configuration.
- Several nominal features, were not implemented yet.
- The main features were the adoption of a new optical layout and heavier test masses



O2

- 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
- Improved Stray Light reduction

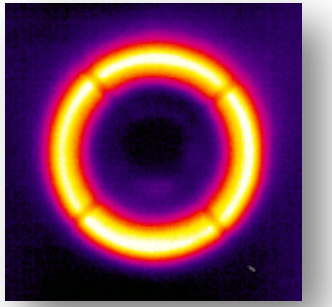
Advanced Virgo layout

The main characteristic of AdV

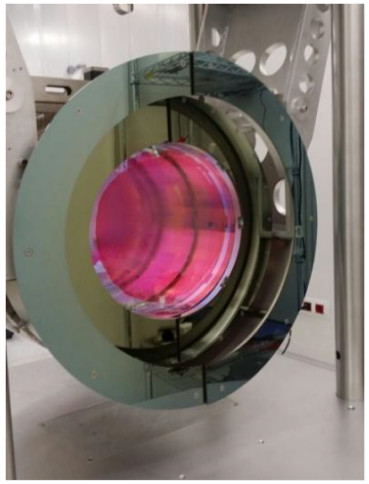
- **SiO2 mirrors**, **350 mm** in diameter, **200 mm** thick, with a residual roughness **< 0,5 x 10^{-9} m**.
- **Monolithic suspensions:** SiO2 fibers **400 μm** in diameter to suspend mirrors **42 kg in weight**.

Other features

- Improved **Thermal Compensation System** to compensate for cold and hot defects on the test masses (100 x higher power on TM)



- Better **vacuum system** (10^{-9} mbar instead of 10^{-7})
  with a total volume of 7000 m^3 is the biggest *ultra-high-vacuum* system in Europe



- Improved **Stray Light Control**

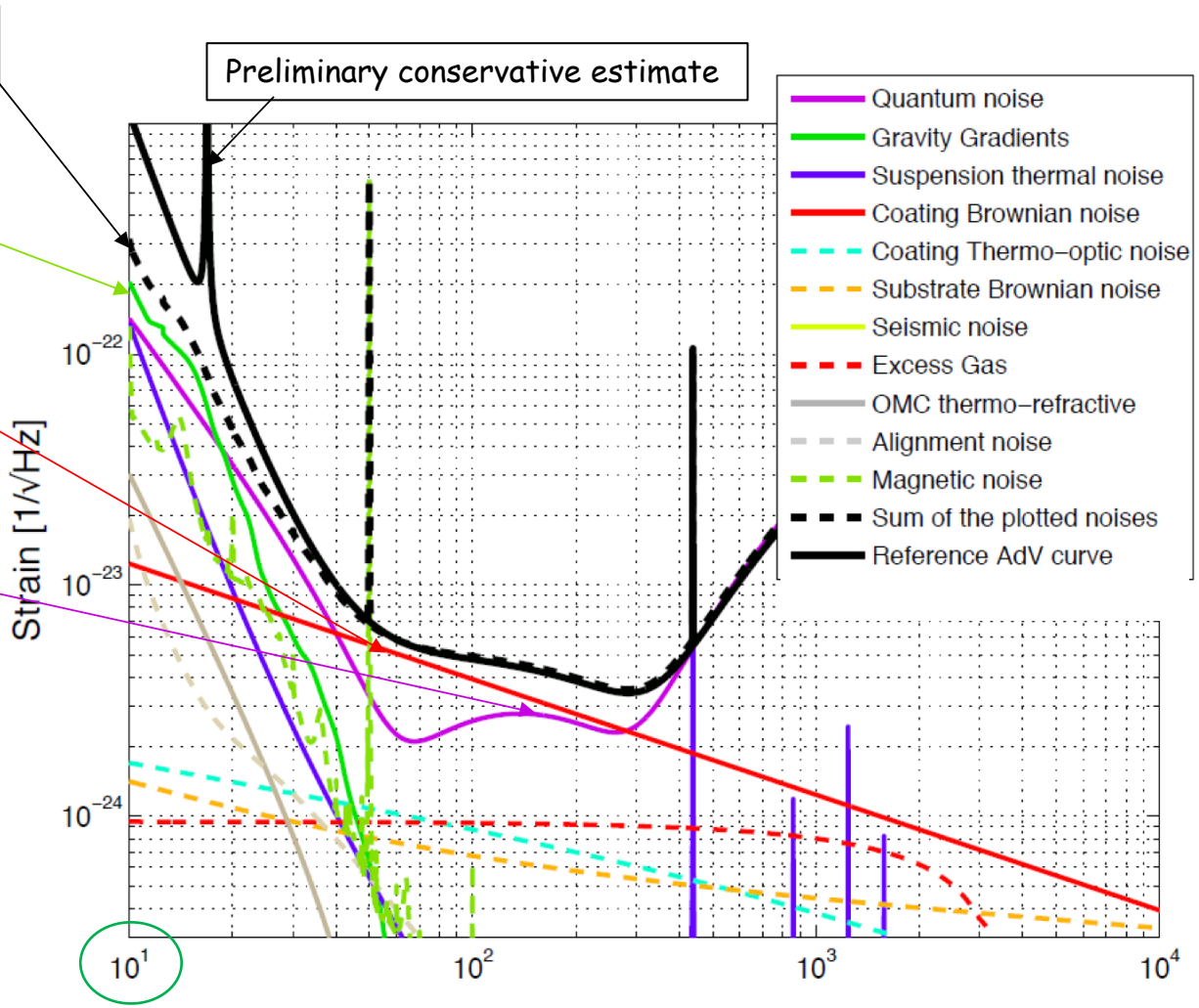
with suspended optical benches in vacuum and new set of baffles and diaphragms to catch up stray light

Target Advanced Virgo sensitivity

Low F:
Gravity Noise (Newtonian/Seismic)

Middle F:
Gravity Noise (mirror coating thermal noise)

High F:
Quantum Noise



Class. Quantum Grav. 32 (2015) 024001

After O2 (i.e. after the first detection + further observations using Virgo)

We try to recover at least partially the nominal sensitivity design

Target Advanced Virgo sensitivity

priority

❑Upgrades before O3

I. Monolithic suspensions

II. Vacuum system modifications

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

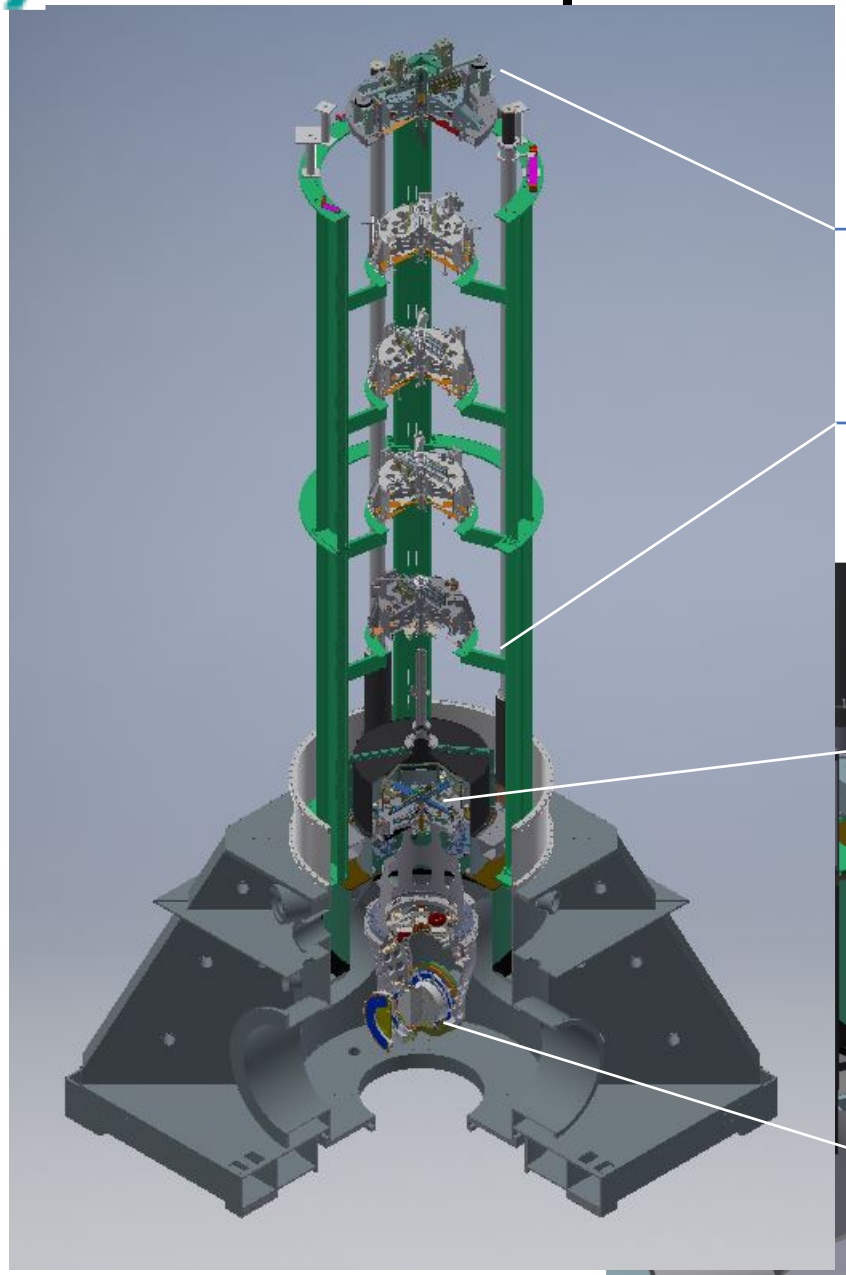
III. Squeezing (AEI)

IV. LASER amplifier integration

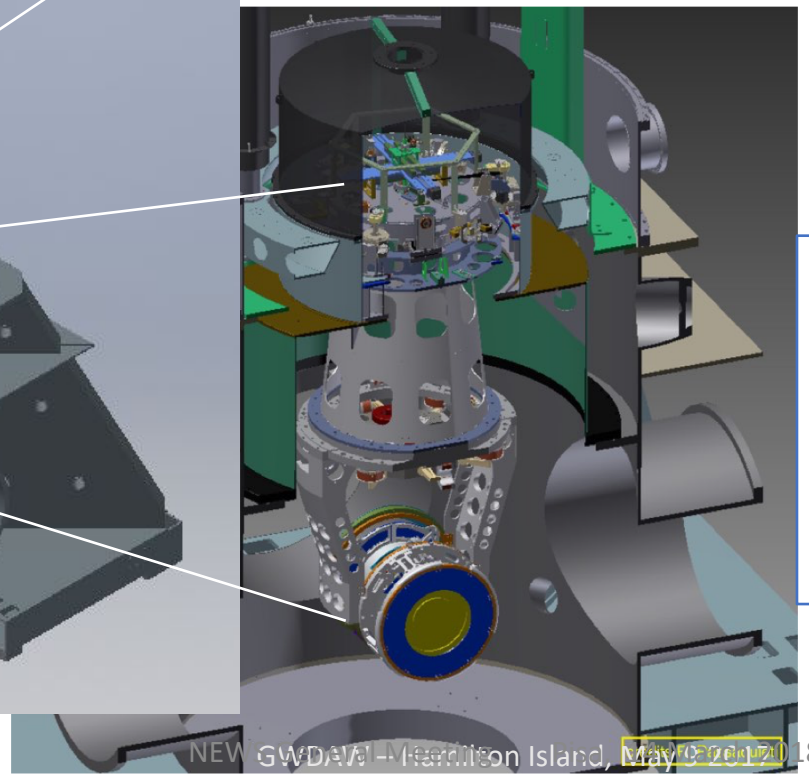
V. Integration of seismic sensors deployed around ETM for NN studies (monitor)

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

Test mass suspensions and seismic isolator: *overall system*



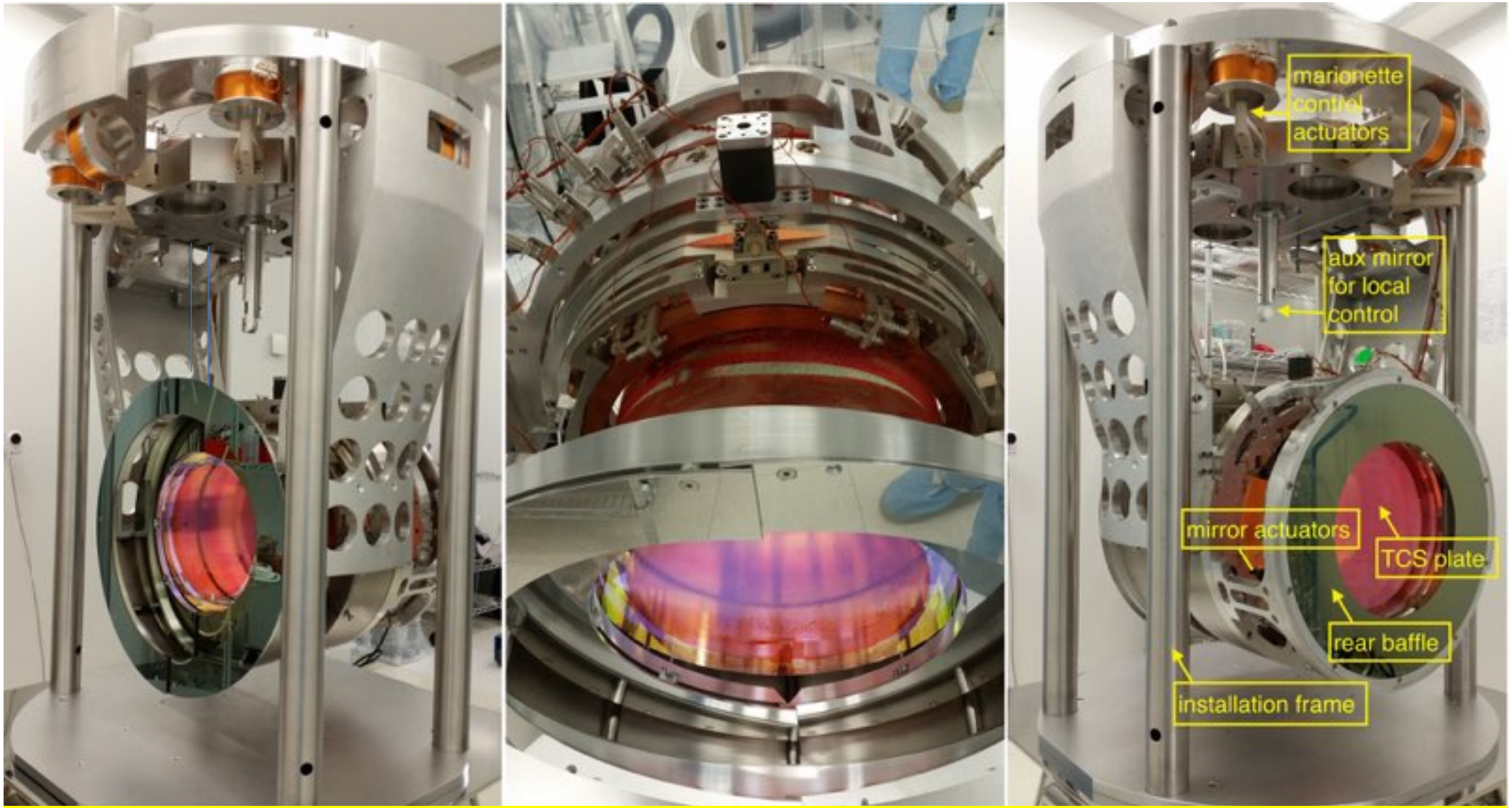
In AdV the first 5 stages of the Super-Attenuator (horizontal and vertical) are the same as in initial Virgo.



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

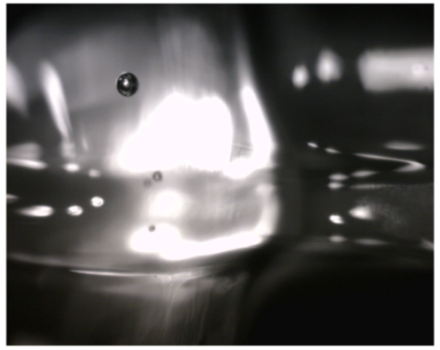
Monolithic suspensions: *AdV payloads*

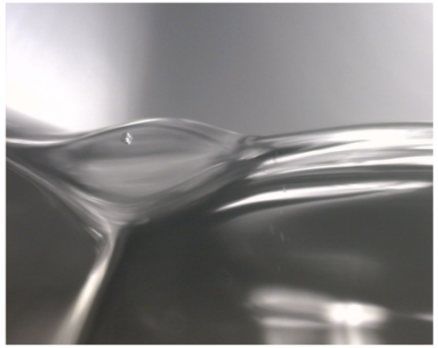
0.4 mm diam
fused silica
Fibers x 4
to suspend
42 kg fused
silica mirrors



Monolithic mirror suspension (same technology successfully used in V+, 2009-2011), adopted to reduce thermal noise, during AdV upgrade had been, for a while, a trouble

Monolithic fused silica suspension *breaking failures nightmare:* typically weeks after installation, at rest, under vacuum





Evidences of isolated bubbles in 3/8 cases

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

- 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)

Null identification of critical parameters

Investigation tools integrated in the procedure

Implementation of **non-critical improvements**

On October 13th, 2016, just after the last fused silica suspension breaking, *we realized the event was clearly correlated with vacuum operations*

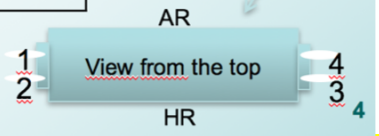
Material investigation study states that all the breakings failures started at the level of the fiber and not at the clamp/welding

Table of Payload Failures, *updated to Oct. 12 2016*

Failed Mirror	Failure date	Time in air	Time in vacuum	Failed Fiber	Anchor type	Likely cause
WI (1st assembly)	Nov 18th, 2015	5 months	9 days	3	old	Anchor collapse
NI (1st assembly)	Dec 18th, 2015	4.5 months	5 days	2	old	Fiber/welding failure
NI (2nd assembly)	Mar 1st, 2016	1 week	5 days	2	new	Fiber/rod failure
NE	Oct.12 2016	6 months	4 months (currentl	TBD	new	TBD
WI dummy (1st assembly)	Apr 25th, 2016	1 week	11 days	1	mixed old	Anchor collapse
WI dummy	No failure	2 days	2 weeks		mixed old	No failure
WI (2nd assembly)	June 25th, 2016	1 month	30 days	3	new	Fiber/welding failure
WE (1st assembly)	Jun 28th, 2016	7 months	18 days	3	new	Fiber/welding failure

New identification of failed fiber, after revision of Aug.2016

Mirror Reference System

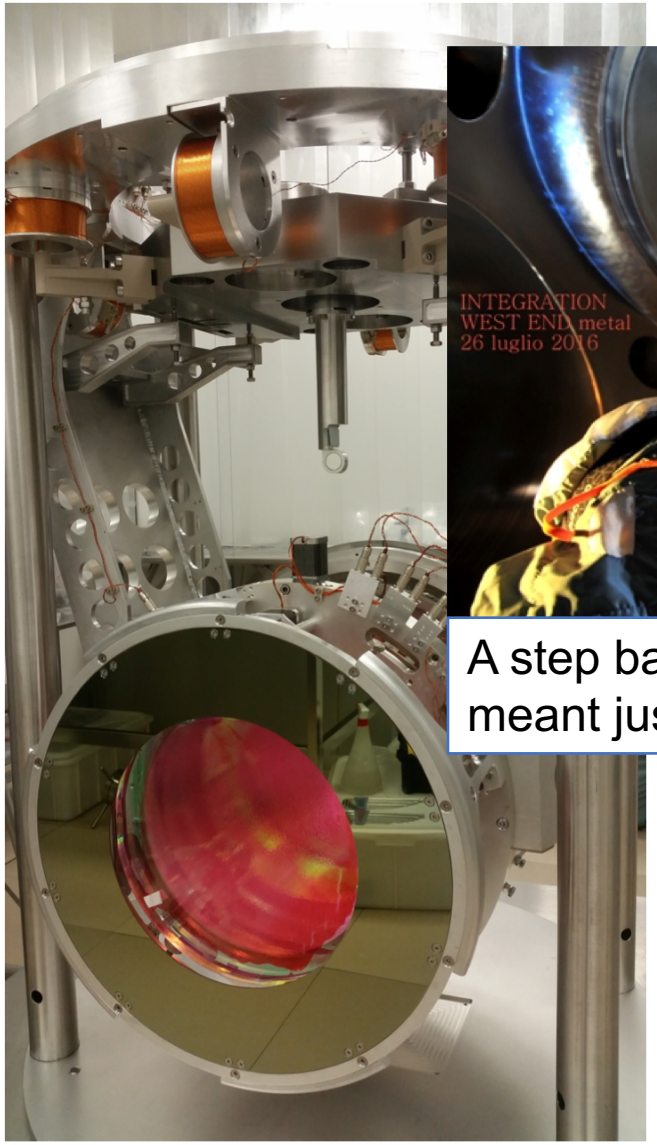


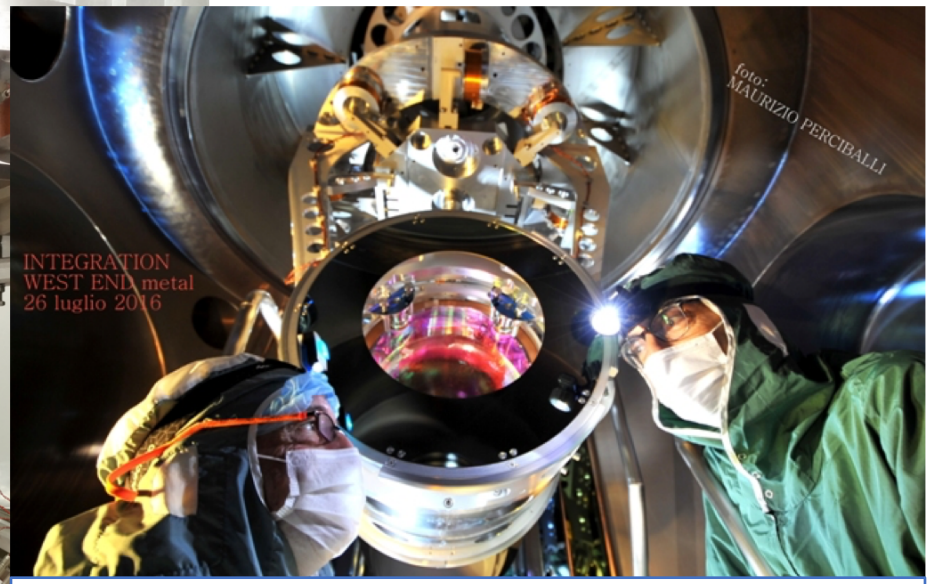
…from the report to the STAC, October 18th 2016

Piero Rapagnani – Virgo Week January 24th 2017

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

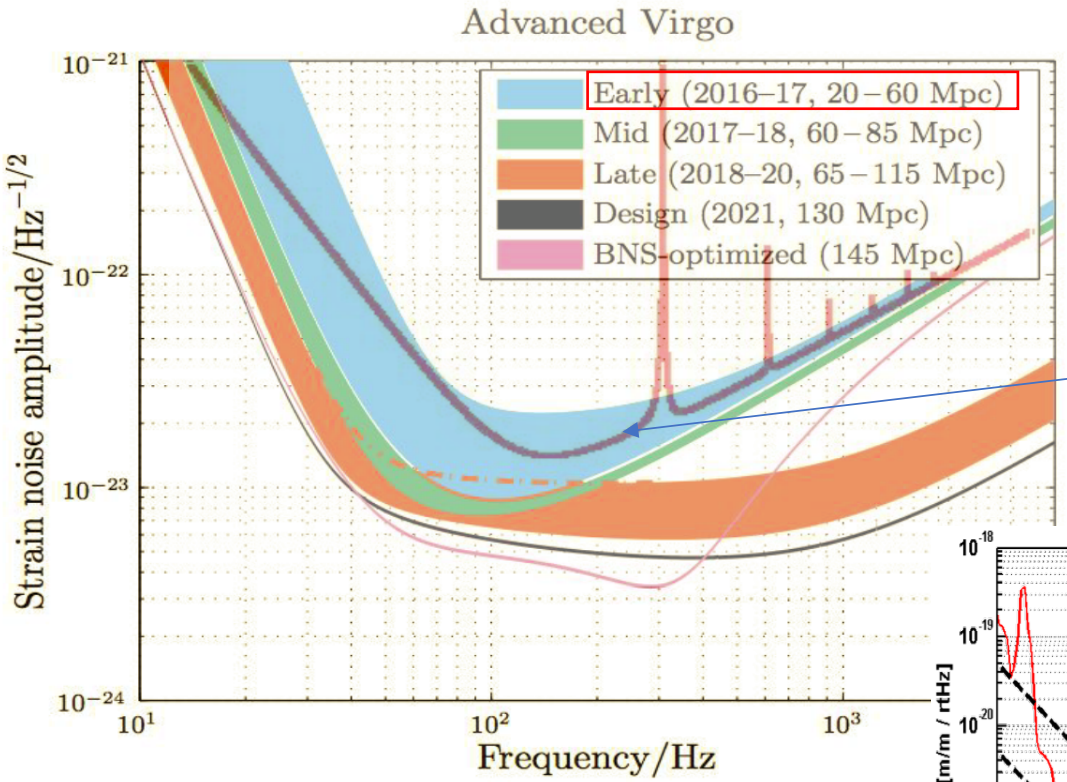
Monolithic suspensions: *readapting payload to steel wires to join O2*



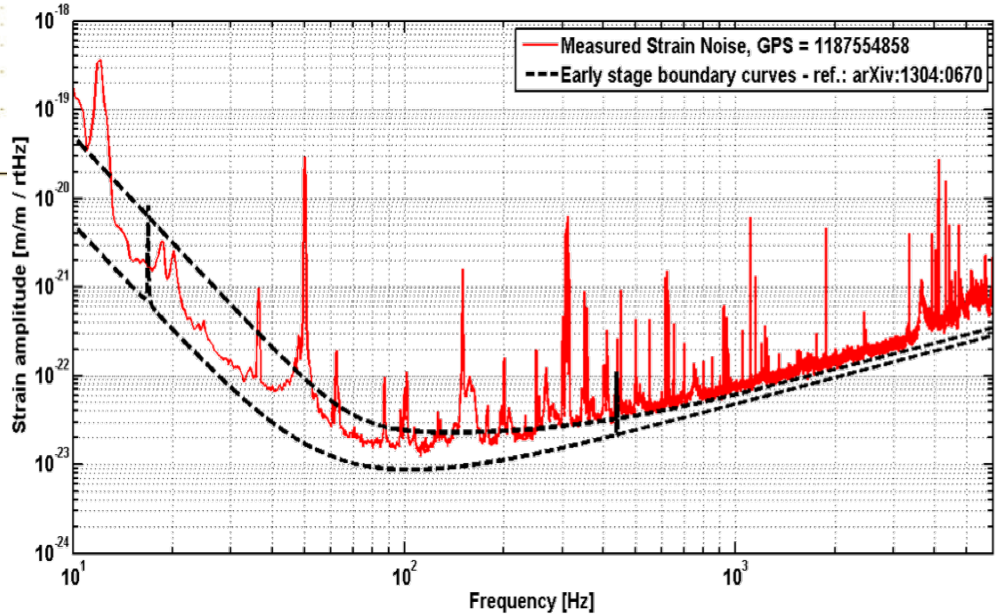


A step backwards (with respect to V+ !)
meant just to allow AdV commissioning

Monolithic suspensions: *sensitivity VS steel wire backup*



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



Steel ($\phi=10^{-3}$)

Horizon NS-NS - 45 Mpc

Horizon BH-BH - 202 Mpc

Monolithic

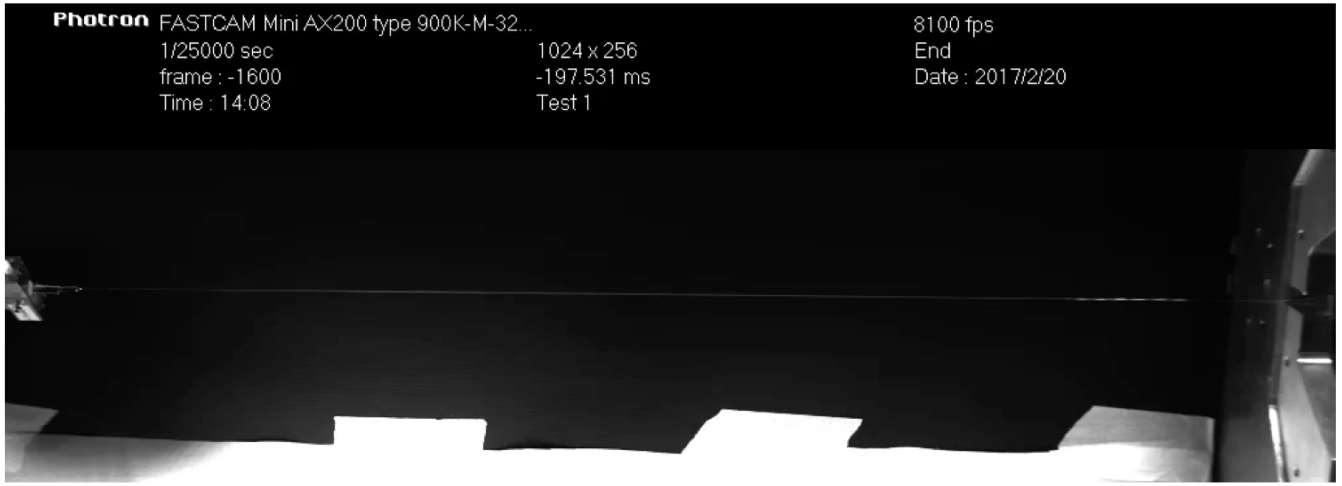
Horizon NS-NS - 101 Mpc

Horizon BH-BH - 985 Mpc

BNS range ~ 28 Mpc → ready to join O2!

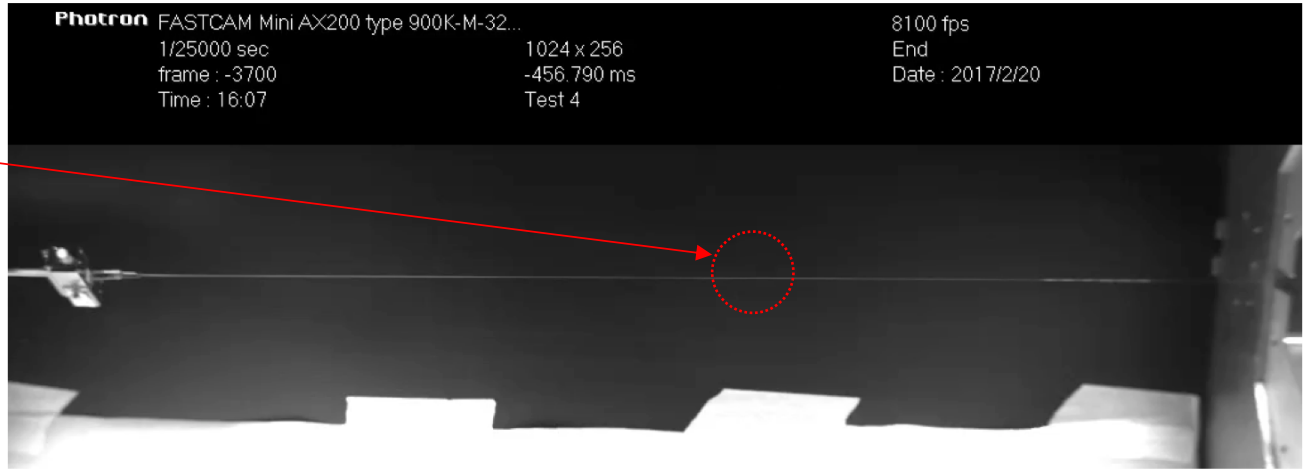
Fused silica fibers : *monitoring tool to study breaking in real time*

Breaking strengths tested in any part of the suspension structure
(high speed camera)



The case of a failure due to the breaking of the fiber head

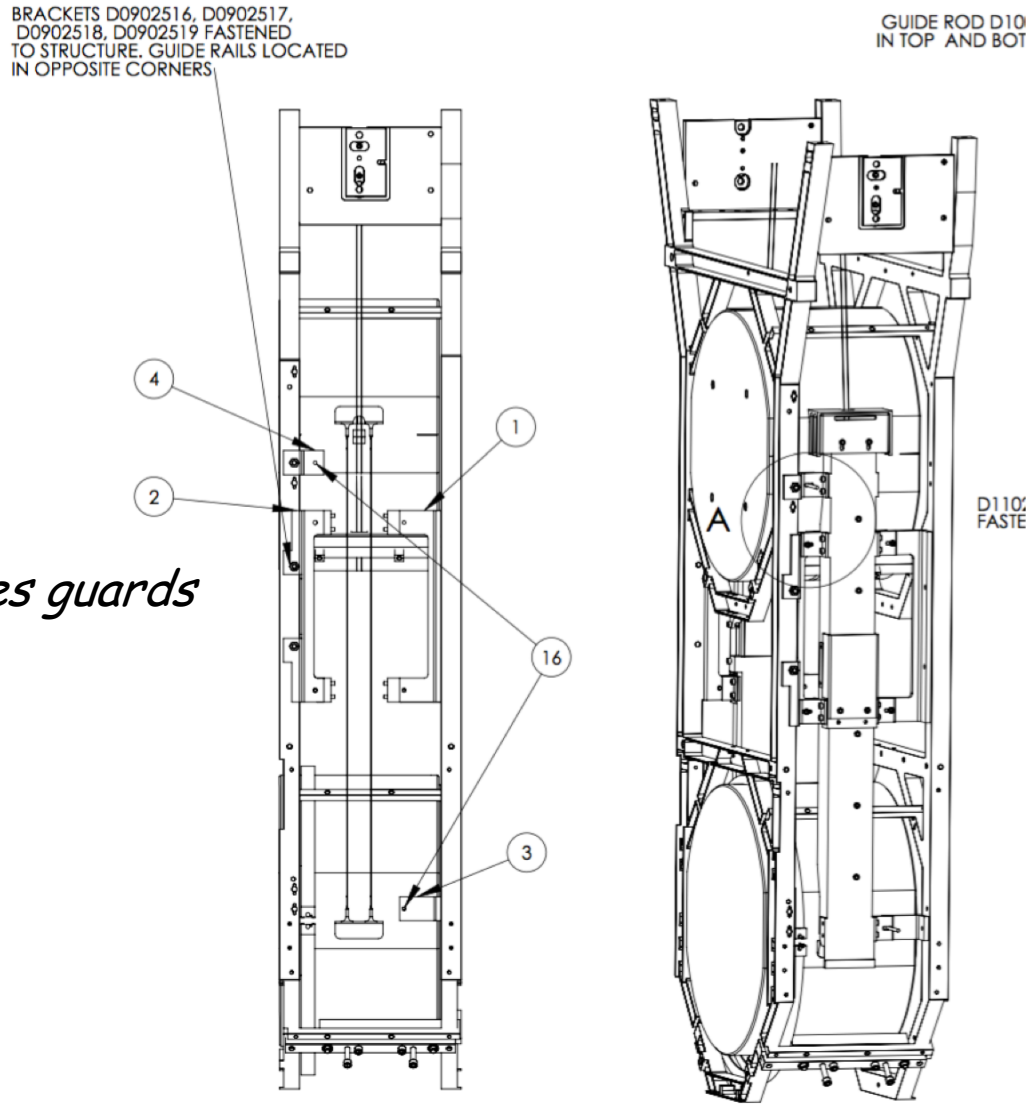
The case of the **fiber** breaking **<u>after</u>** a gentle touch (unloaded)

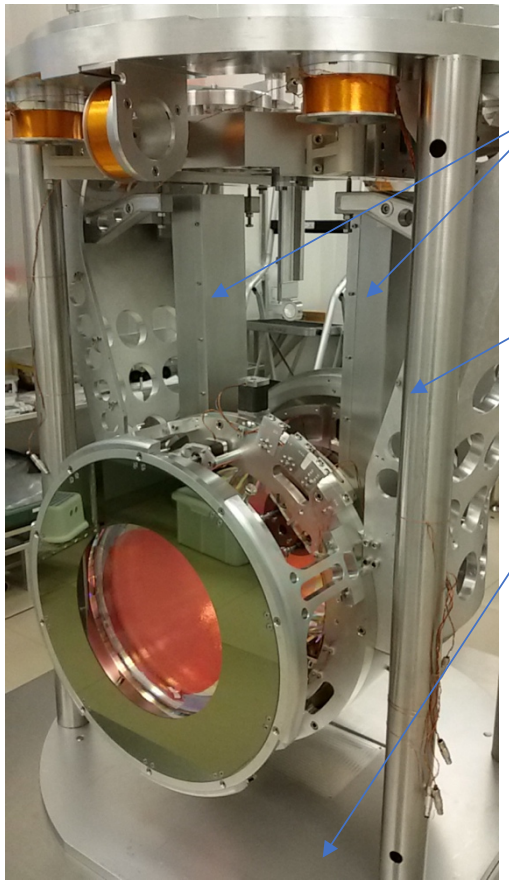


Trouble on Monolithic suspensions, solutions:

Fiber guards to protect fibers against any external mechanical agent

Also LIGO sues guards



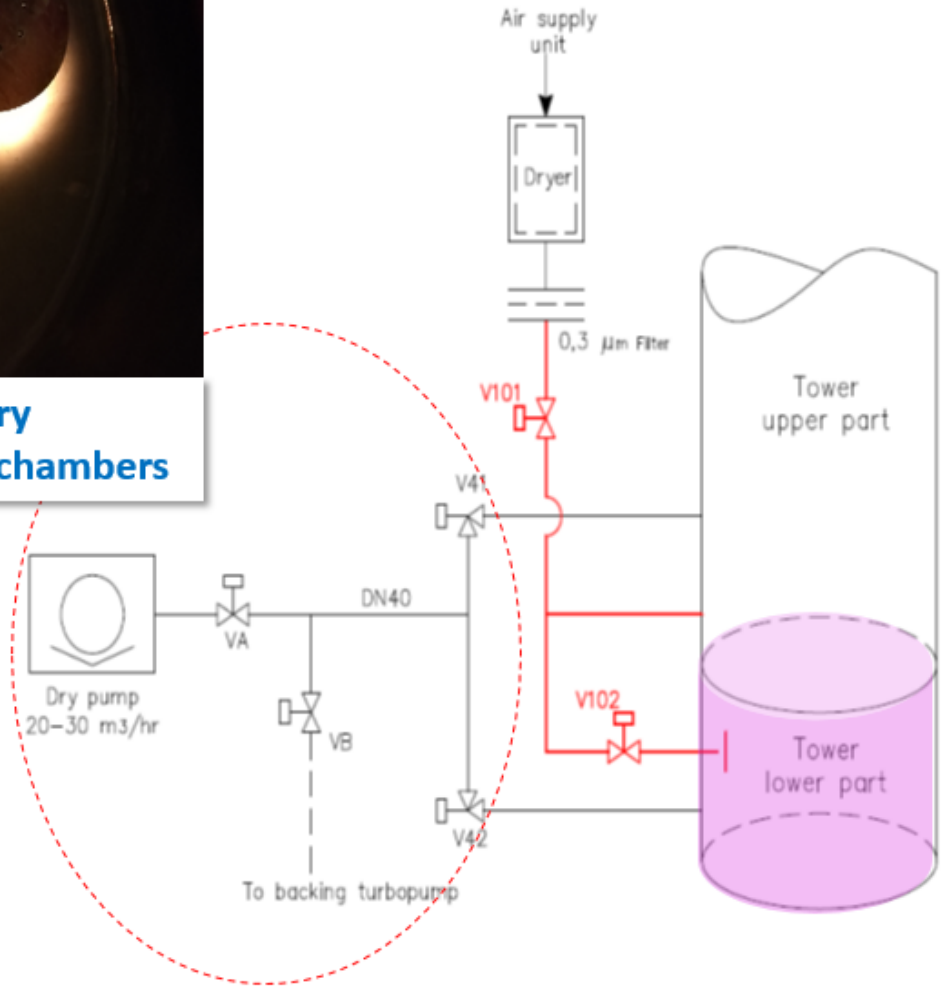


Trouble on Monolithic suspensions, solutions:
vacuum system revised

1) Venting circuit separation

3) Extraordinary cleanliness of chambers

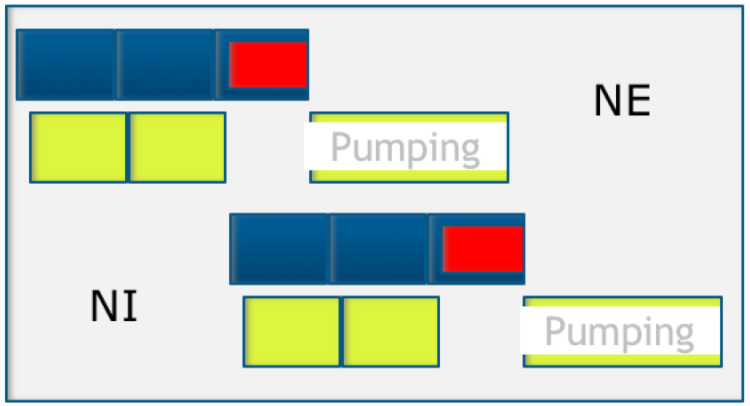
2) Scroll pump substitution



O3 starts in fall 2019!!!

planning rush, parallel compression, accuracy

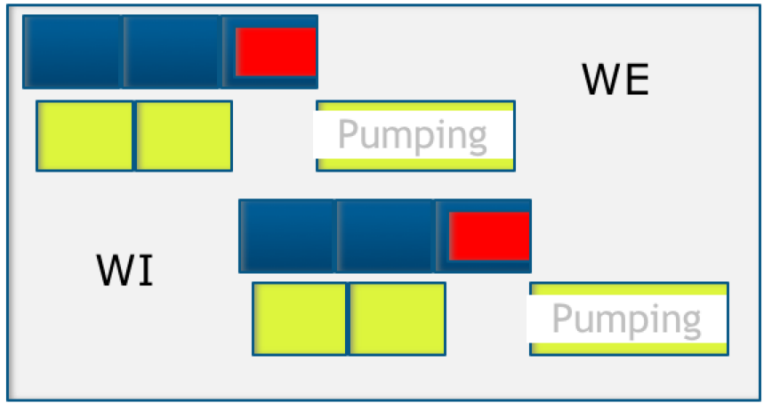
Monolithic suspension re-installation



North arm installation
6-7 weeks

2 weeks

West arm installation
6-7 weeks



Payload re-suspension

Vacuum upgrade, cleaning

Commissioning with ITF locked
Other installations

14-16 weeks

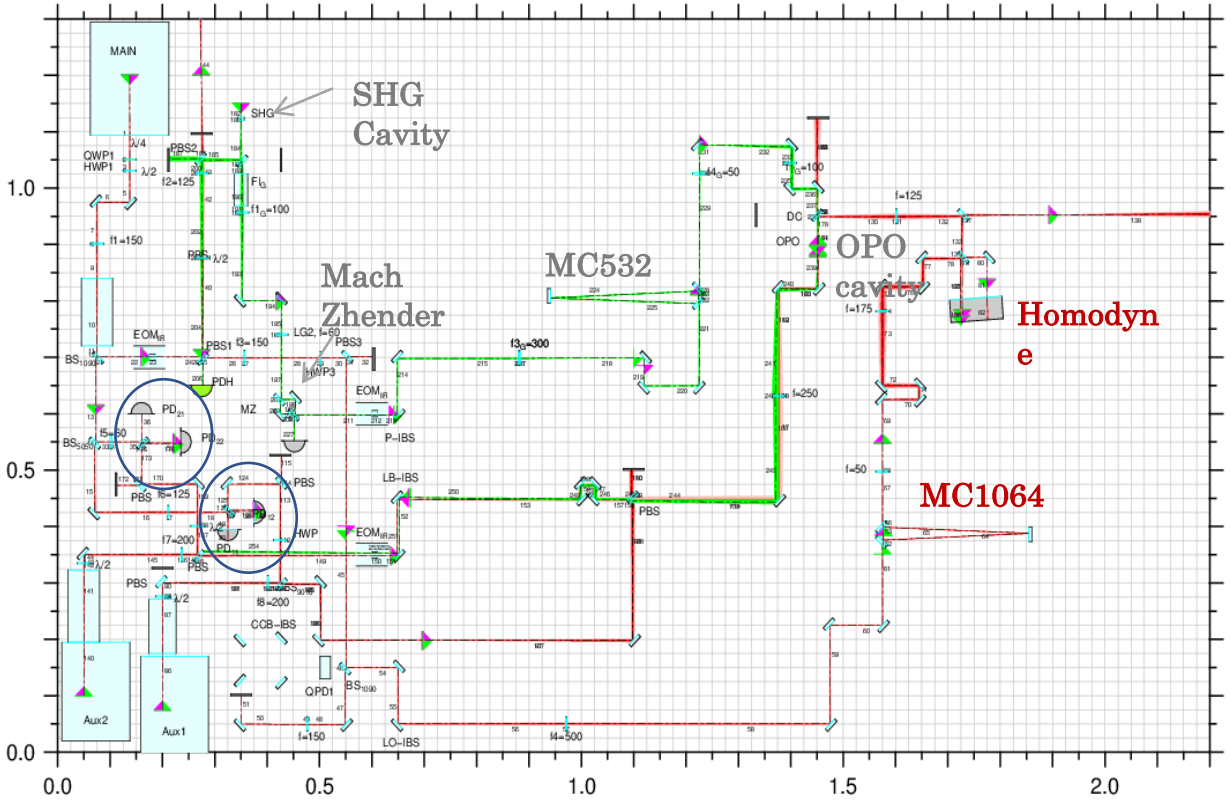
Done in 14 weeks

including recovery of four unforeseen issues (2 weeks)

other installations : Squeezed light bench at the detection port, to reduce quantum noise without increasing the power

In the last two years a local development of squeezed light prototype bench for AdV took place at the site.

- A dedicated infrastructure was set up from scratch at Virgo site (supported by European Grav. Observatory)
- The optics and the controls have been set up and the system is starting to be tested

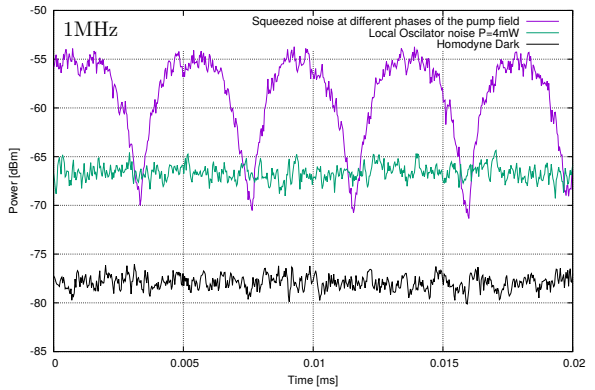


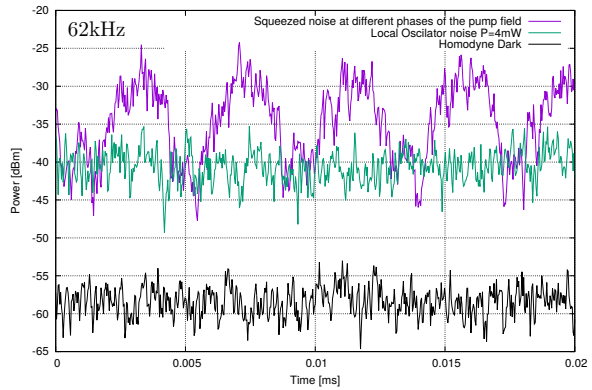
Green Line SHG+MZ+MC532

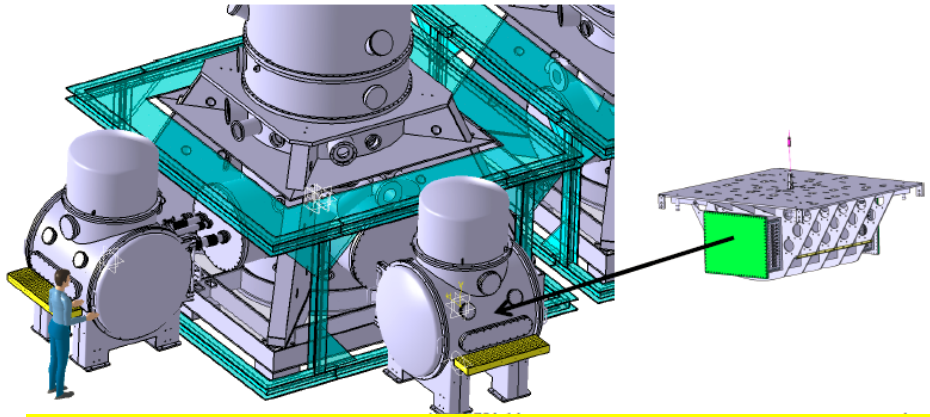
Homodyne line MC1064+ homodyne

OPO Line OPO cavity

Other OPLL, electronics



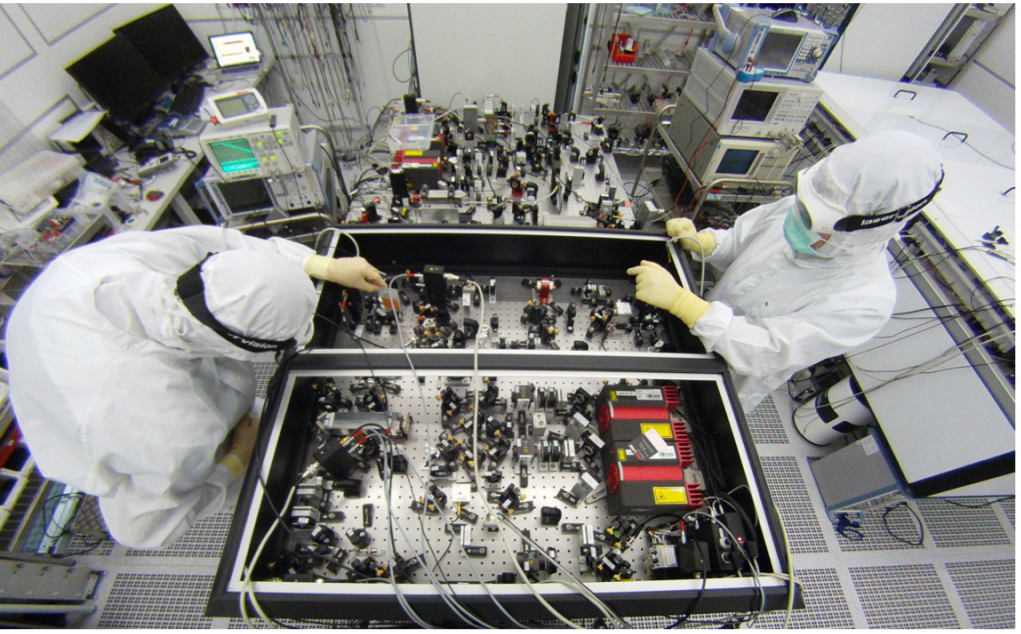




The system is designed to be suspended through a minitower system.

other installations : Squeezing bench (Max Planck Institute AEI !)

December 2016, collaboration agreement with AEI, offering a **plug&play squeezer bench**. (Talk by M. De Laurentis)
➔ Decided to integrate at first this system to leave local SQZ development the time to be fully completed.



Two identical boxes will be developed
The second remains in Hannover for debug

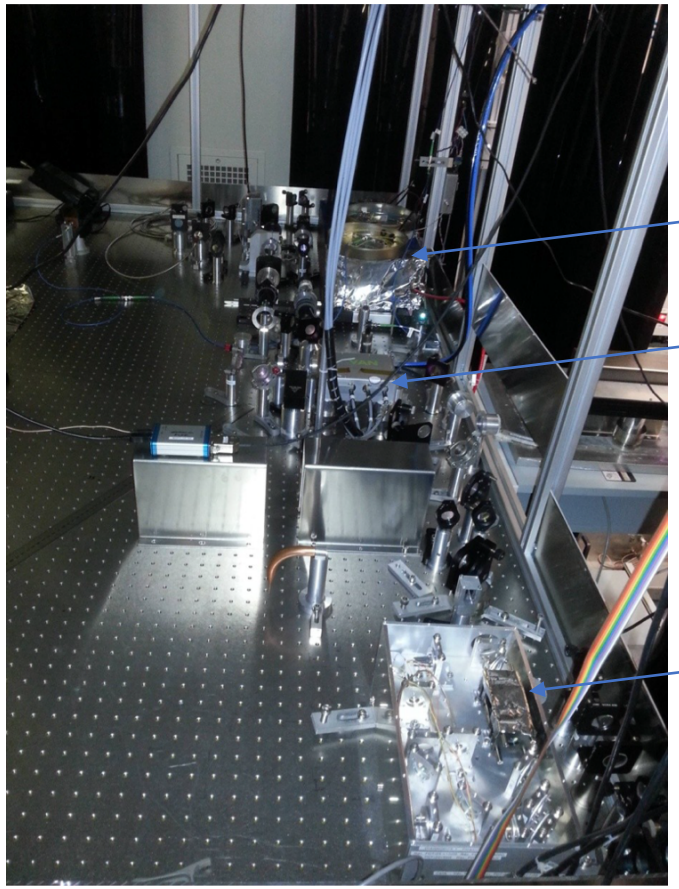
- Very compact breadboard with enclosure 1.2 m^2
- 3 Faraday isolators, matching Telescope, autoalignment system
- Doubly Resonant OPO (532 and1064 nm).
- Placed on a bench equipped with elastometers (AdV SQZ)
- Environment: under laminar clean airflow, $\Delta T \sim 0.5$ C OK
- AEI electronics rack to be integrated in AdV system
- Digital control HW and SW integrated in the overall system (AdV SQZ)
- Large flange of Detection Susp. Bench has to be adapted
- Access to suspended Detection Bench to integrate components
- Locking the squeezer on the Virgo laser via OPLL.

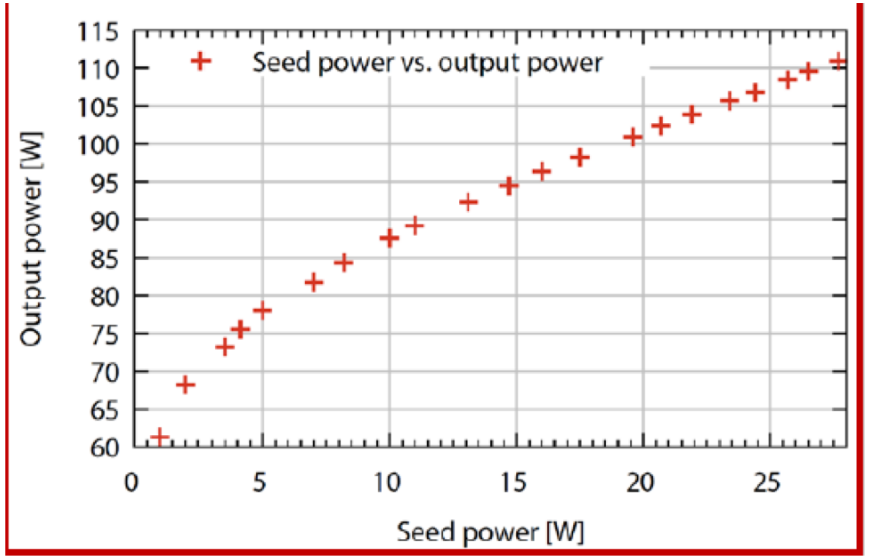
Squeezer commissioning completed by the summer, it will be in operation during O3 (it allows to gain sensitivity at HF without injected power increase.

INCRESING INJECTED POWER (nominal design 125 W)

- Modified NeoVAN amplifier (104W output, seed 20W) pre-tested at AEI
- Validation/long-term test at ARTEMIS (Virgo, Nice) showing up HOM < 15% (versus 10% at AEI)

- NeoVAN amplifier easily integrated in AdV injection system
- IMC needed during the integration

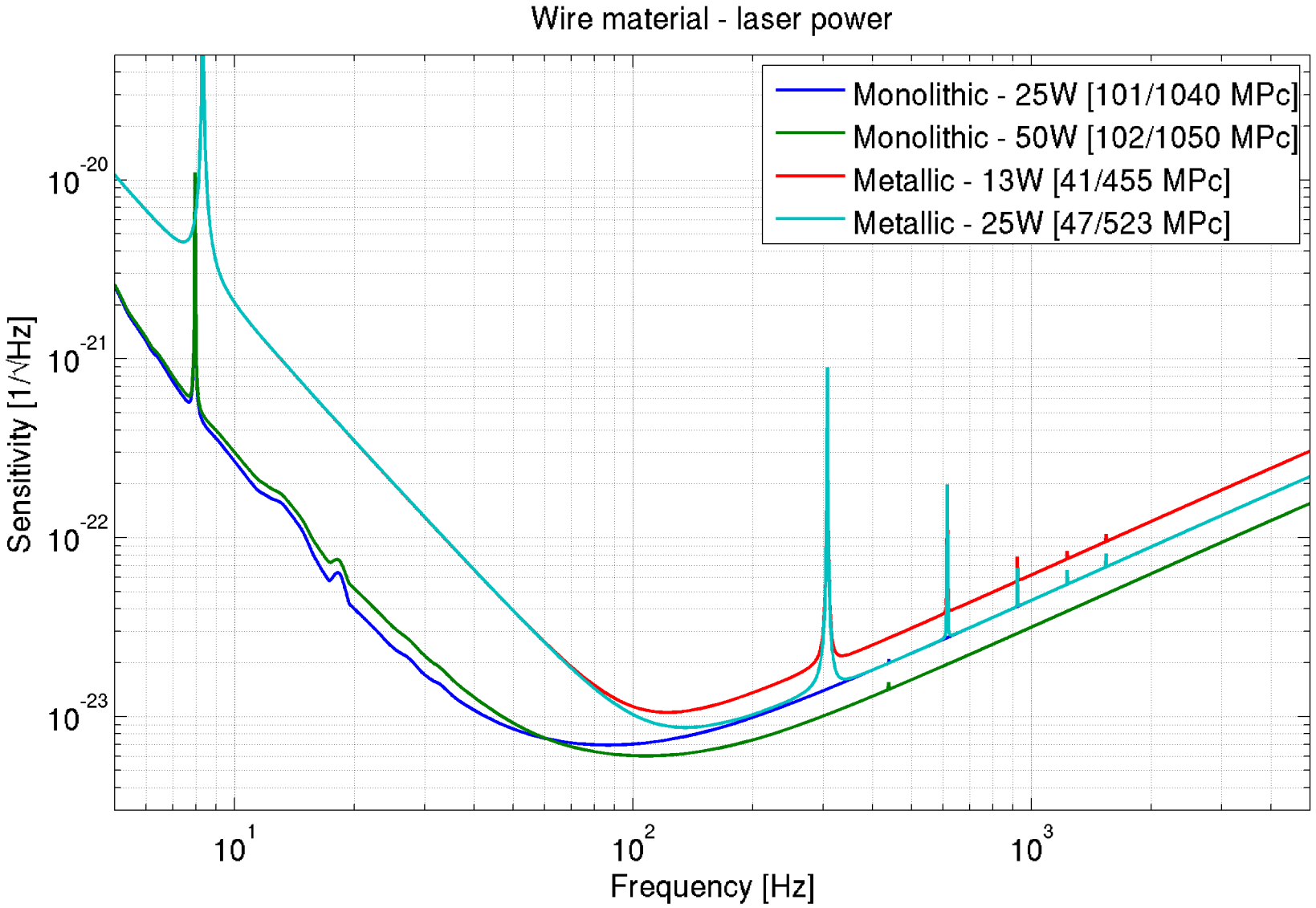




- Actual possibility to join O3 using 50 W injection
- Decision deferred to the summer, after reliable operation at 25 W and sensitivity achievements

Sensitivity curves: Power/Squeezing/Signal-recycling parameter prediction (by G.Gemme)

Injection Power O2➔O3

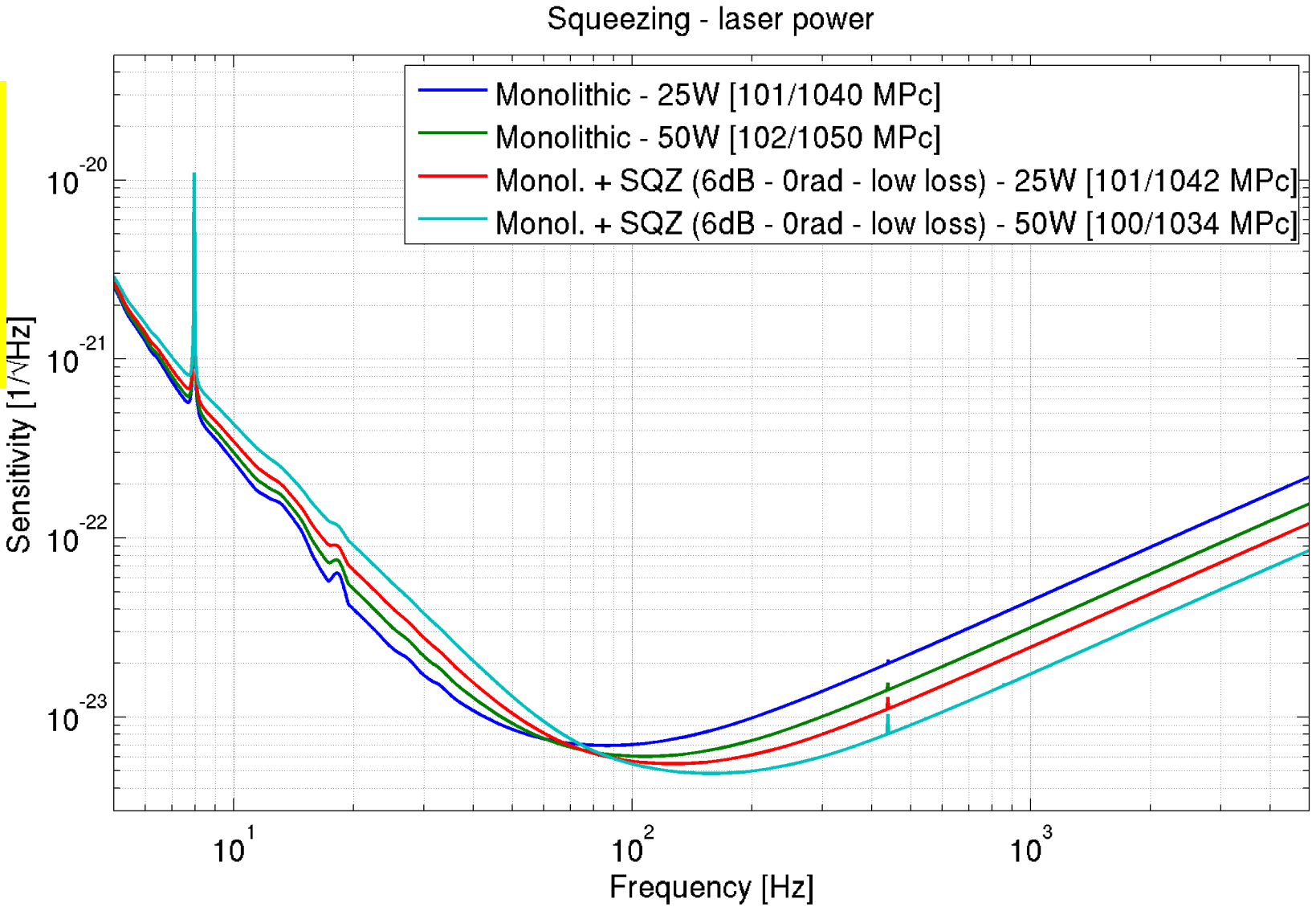


BNS/BBH

Monolithic suspensions improve factor 8 at LF

Sensitivity curves: Power/Squeezing/Signal-recycling parameter prediction (by G.Gemme)

Injection Power + SQZ (O2➔O3)



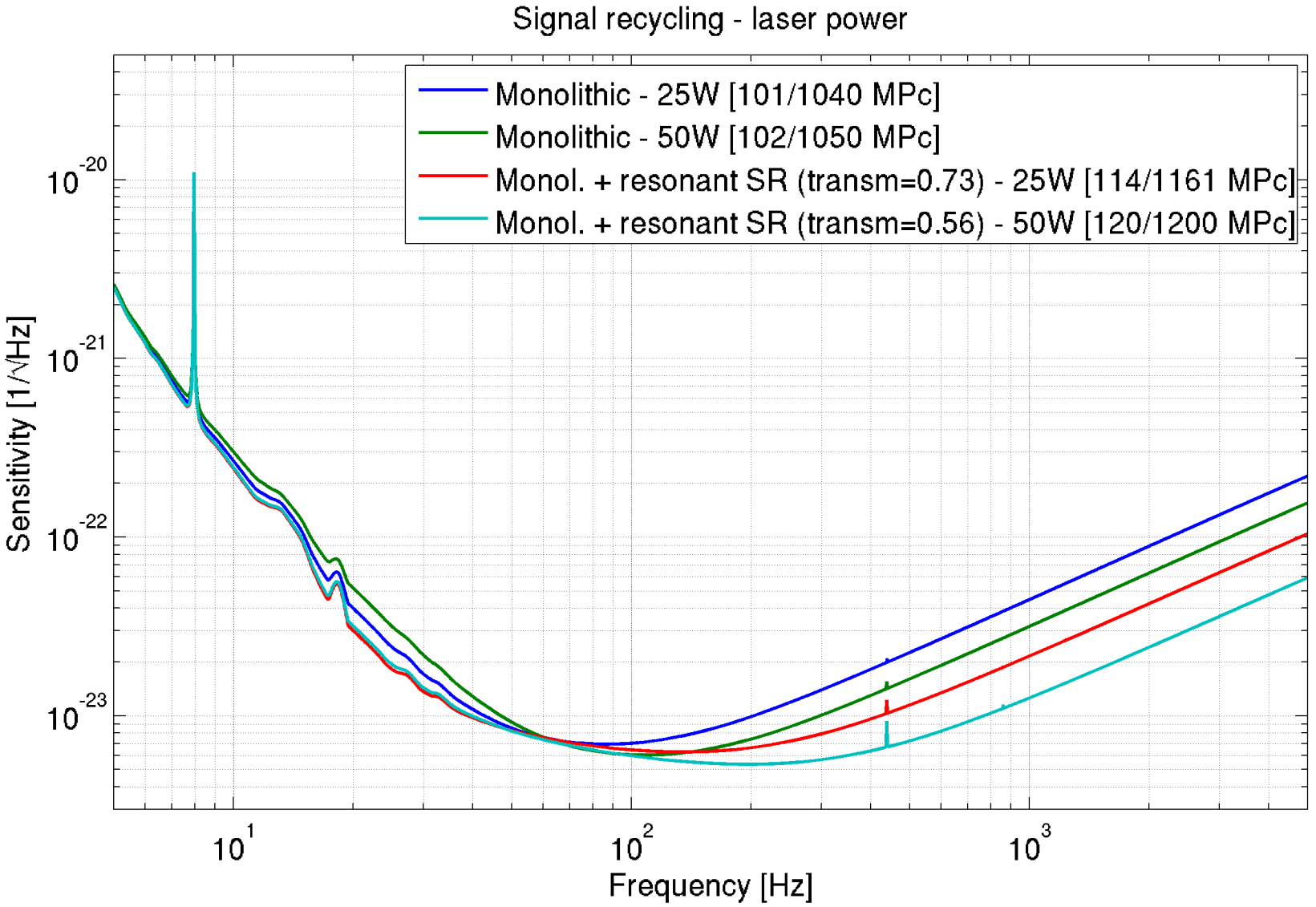
BNS/BBH

- Squeezing angle 0˚ (not optimized)

Power increase / squeezing improve at HF, lose at LF, **a decision will be taken before summer 2018**

Sensitivity curves: Power/Squeezing/Signal-recycling parameter prediction (by G.Gemme)

AFTER O3
Signal recycling



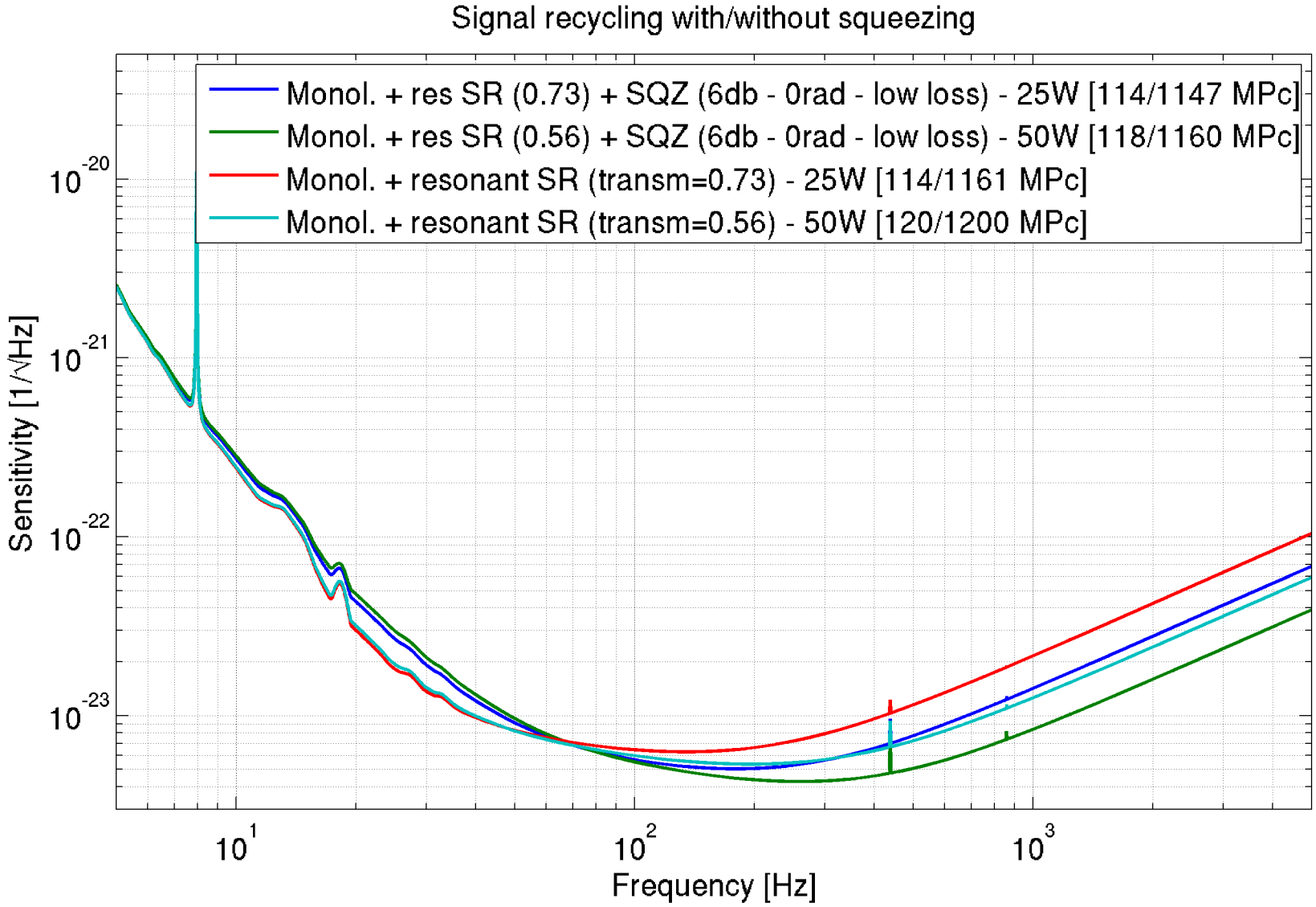
BNS/BBH

- SR mirror transmission optimized for 25 and 50 W cases

Signal recycling improves HF without worsening at LF

Sensitivity curves: Power/Squeezing/Signal-recycling parameter prediction (by G.Gemme)

AFTER O3
Signal recycling + SQZ



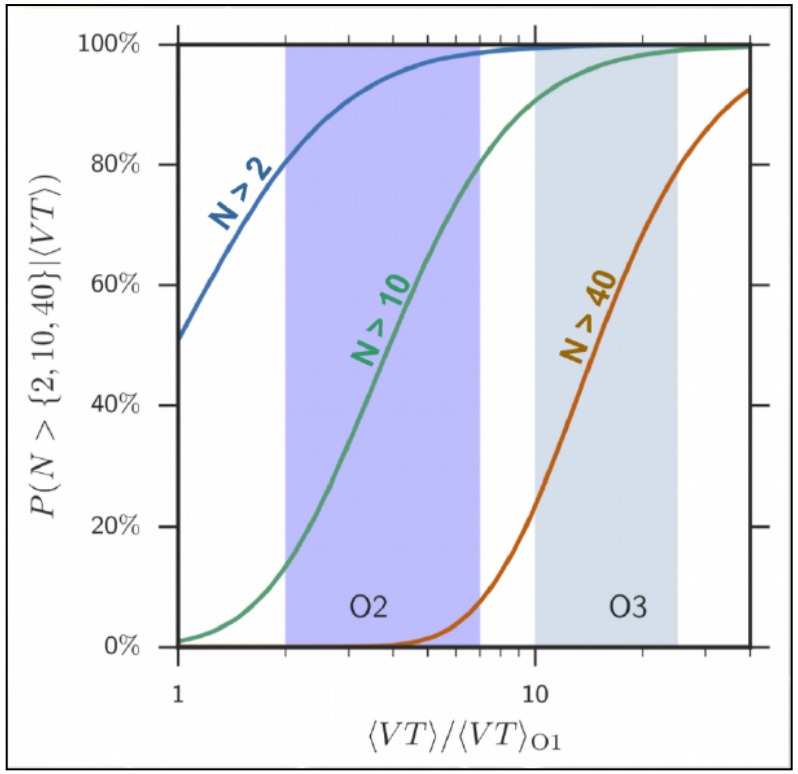
BNS/BBH

Squeezing helps a lot at HF, but worsens at LF

Leading to O3, summary

- 1 year long, starting in fall 2018
- Reduction of thermal noise
  Installation of monolithic suspensions
- Reduction of the quantum shot noise:
  Integration of high power laser
  (more than 3x more power in input)
  Integration of the squeezing bench
- Reduction of optical losses:
  Installation of new Faraday isolators
  and new high QE photodiodes
- Electronic noise optimization
- Better Newtonian noise reduction

BBH rate upon O1 run rate

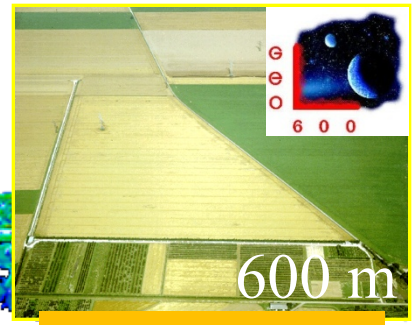


Abbot et al. 2016, PRX, 6, 041015

These upgrades are foreseen to bring the sensitivity to more than 60 Mpc (Mid-stage sensitivity), **through an intensive 3-month-long commissioning**.
Several observations are expected

Worldwide network

Upgrade toward O3



In operation

indigo
4 km

Approved, foreseen to start around 2022

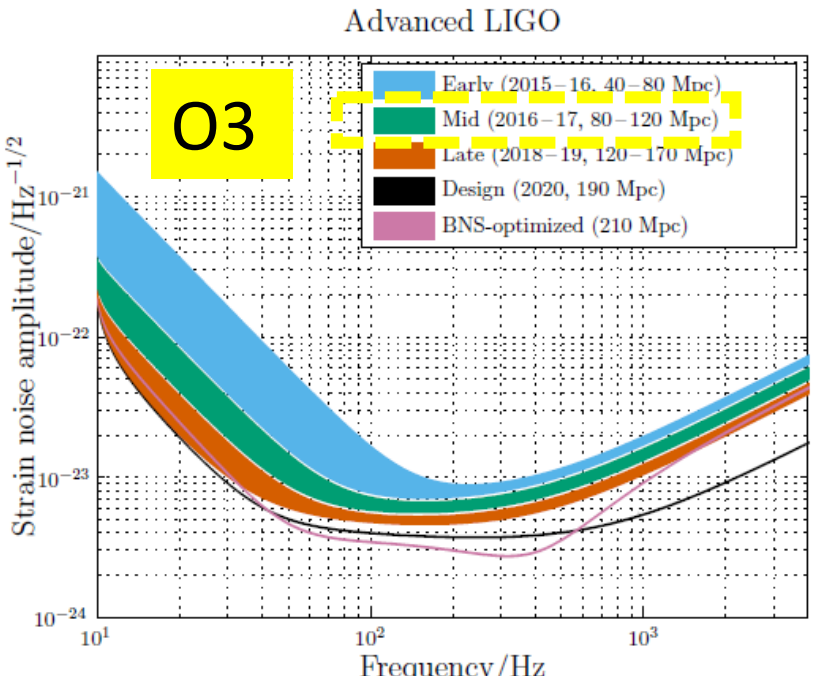
Upgrade toward O3

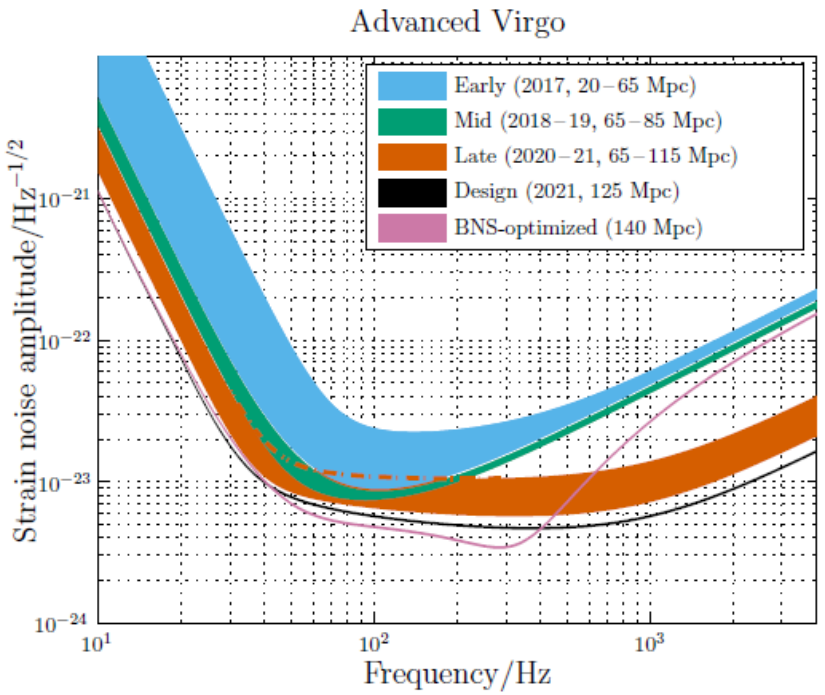
Upgrade toward O3

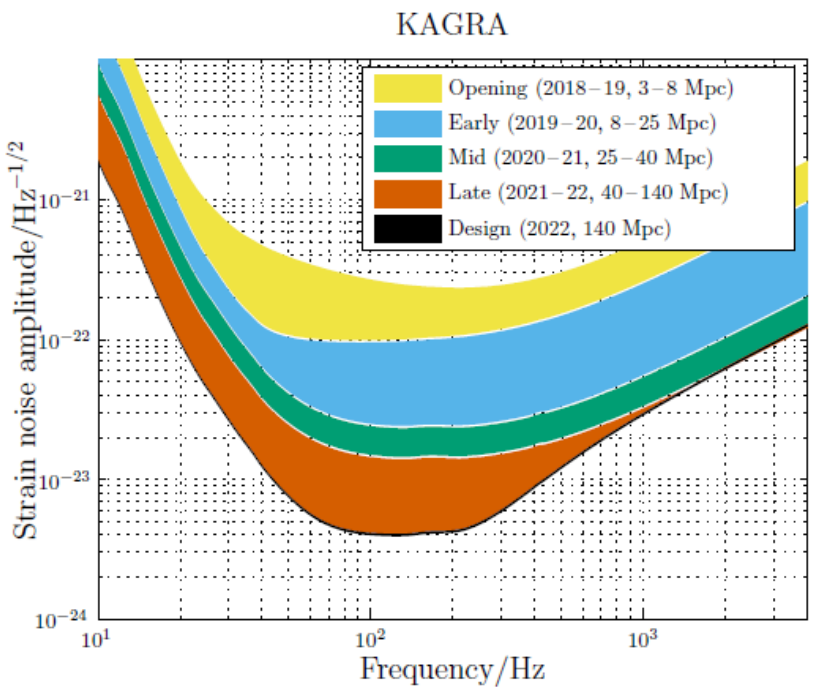
KAGRA
3 km

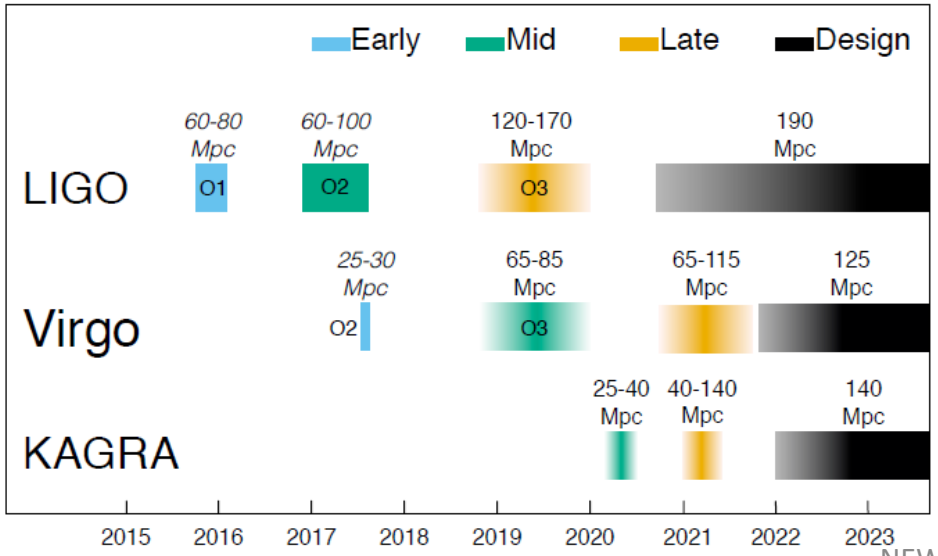
Under construction, operative by the end of 2019

LIGO-Virgo-Kagra observing scenario









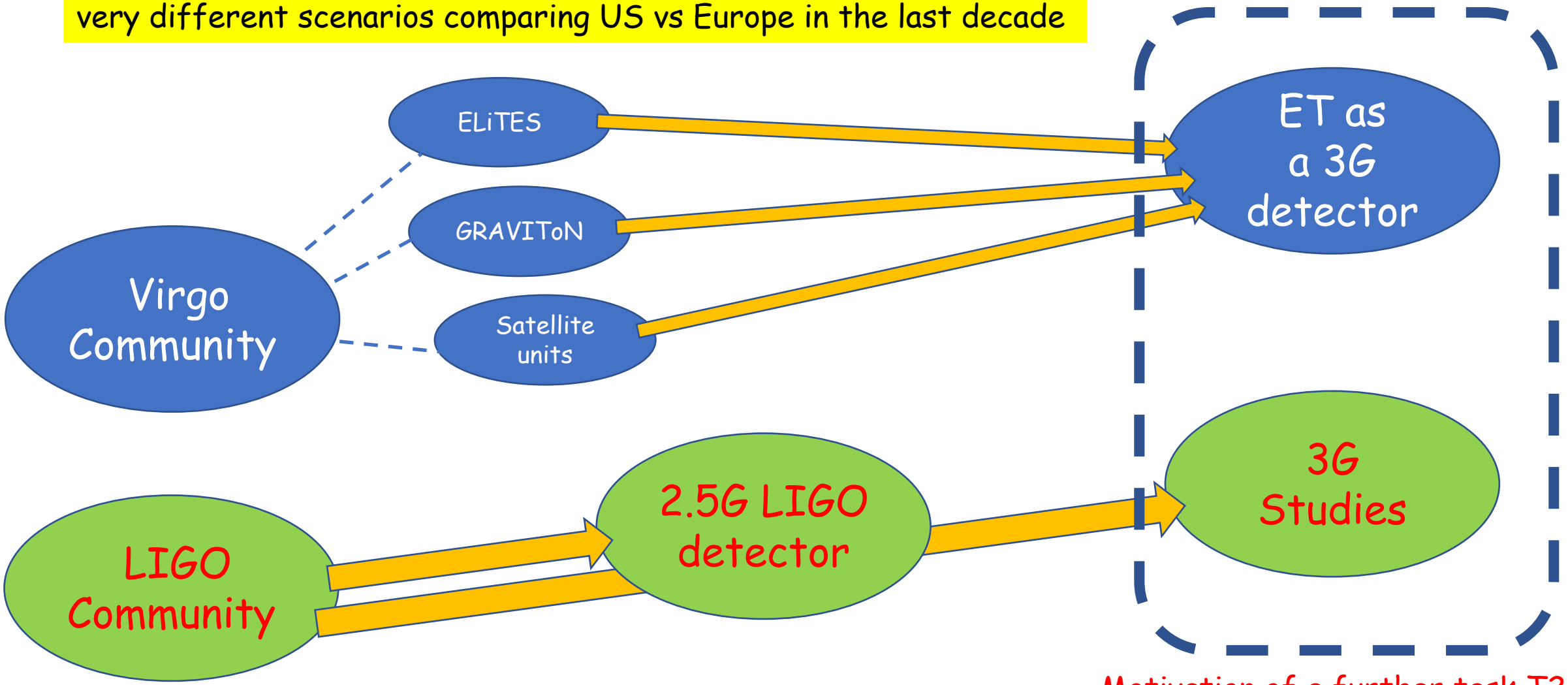
Living Rev. Relativ. (2016) 19: 1

3x range
27x rate

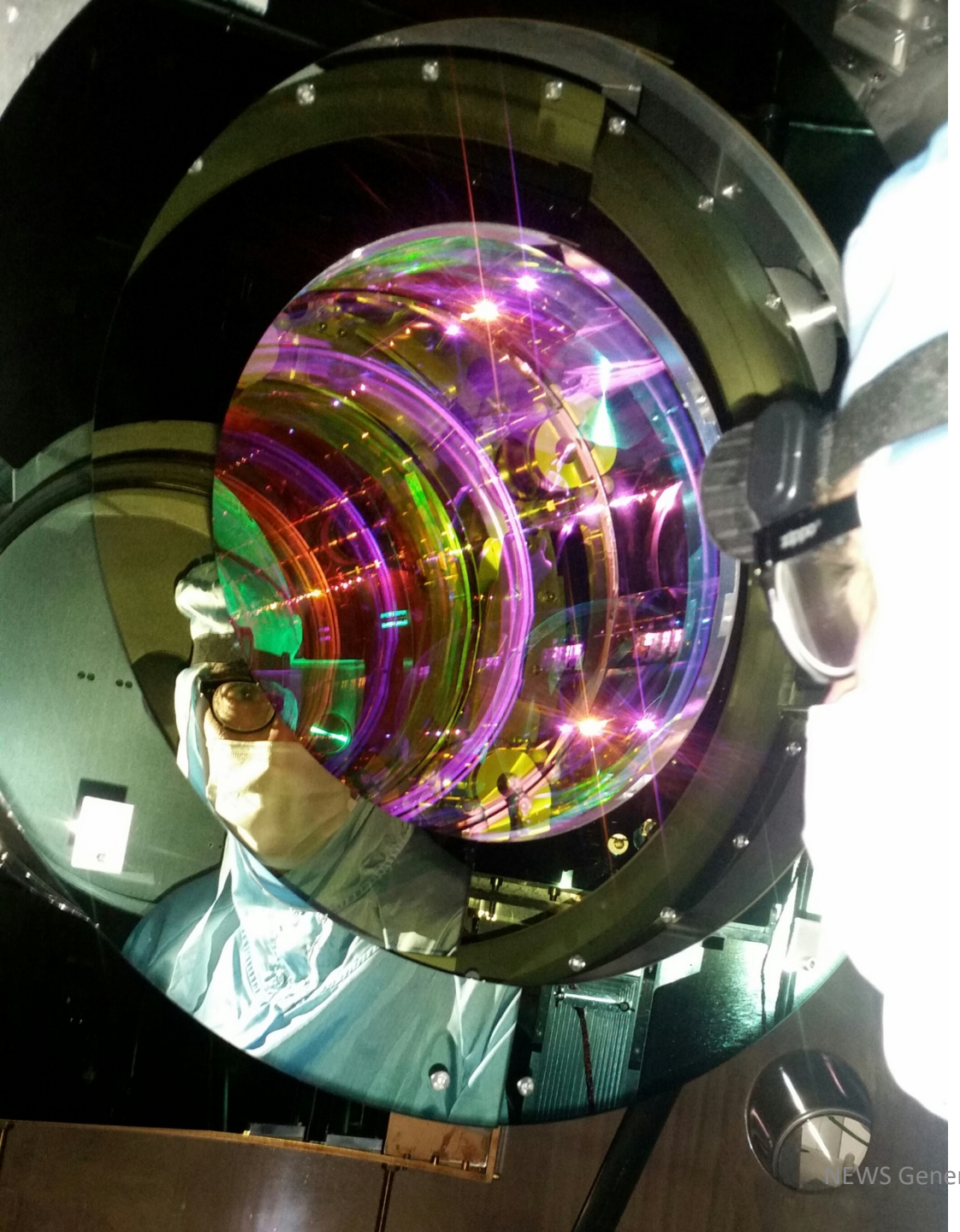
O3 is a very exciting scenario but also KAGRA, which embeds the **seeds of 3G detector** technology, will soon join the network !

A glance to WP2 T2.2 (1-48): Evolution of 2nd generation detectors (2G) towards 3G

very different scenarios comparing US vs Europe in the last decade



Motivation of a further task T2.3



Conclusions

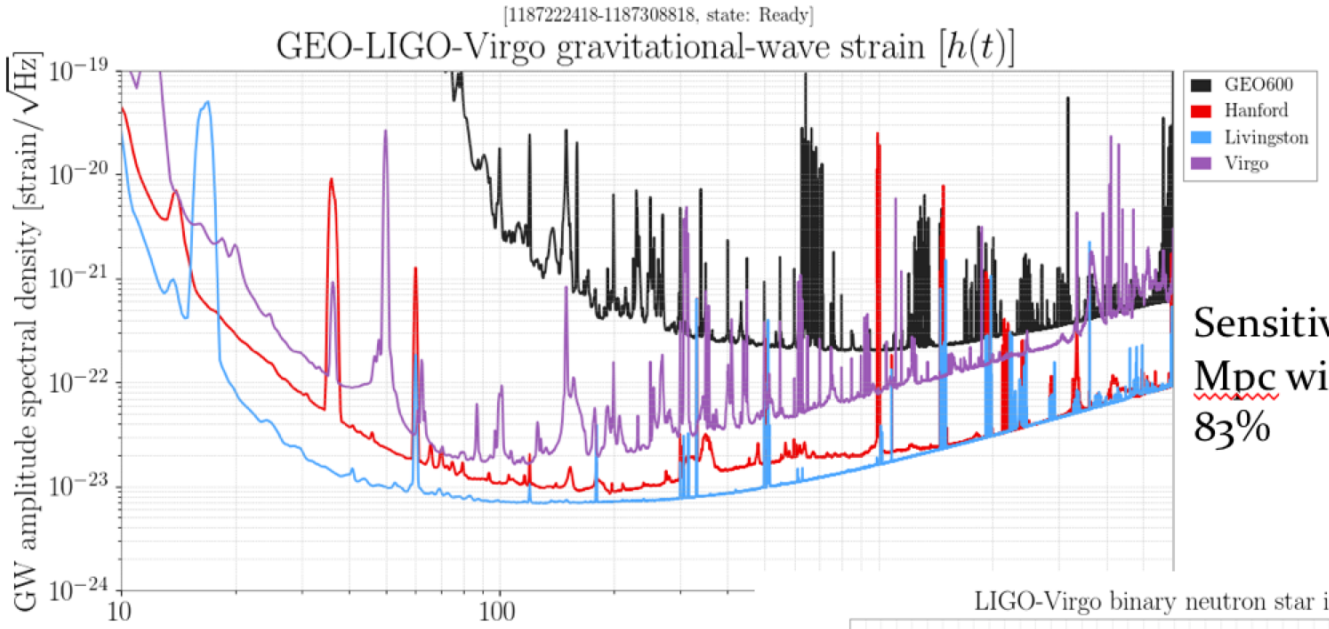
A relevant effort is being dedicated to complete the implementation some key features of Advanced Virgo

Observation run O3 provides a unique opportunity to learn a lot about networked operation of advanced detectors that cannot be missed.

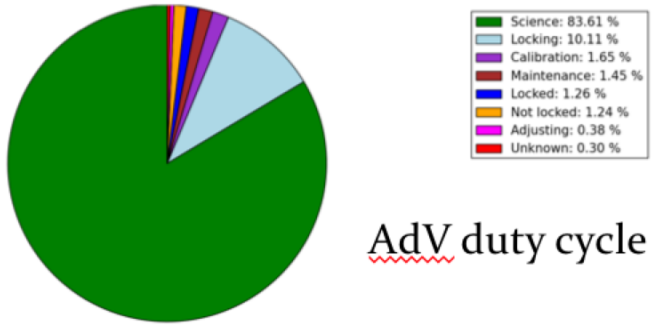
RISE-NEWS is a synergic link between the community of young scientists working on current detectors and that of 3G detectors.

2nd generation detectors performance during O2

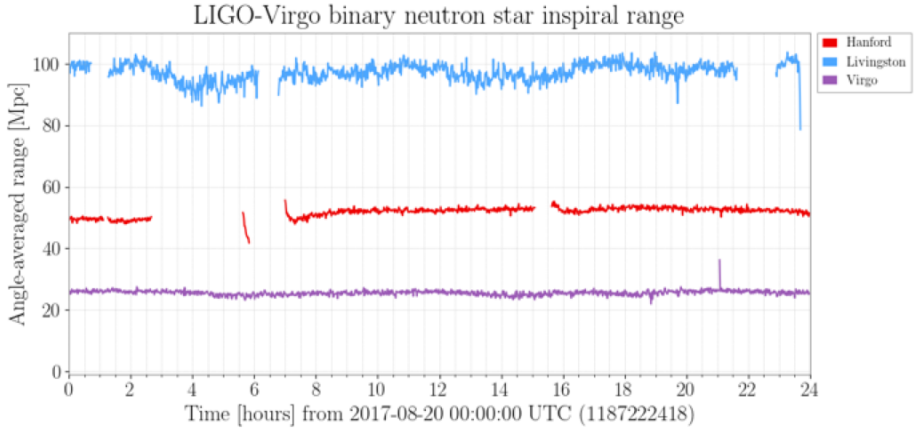
Sensitivity (as of 20/08/2018)



Sensitivity of about 28 Mpc with a duty cycle of 83%



AdV duty cycle



Fermi LAT