Enhancing Advanced Virgo sensitivity with the re-integration of monolithic payloads

Luca Naticchioni

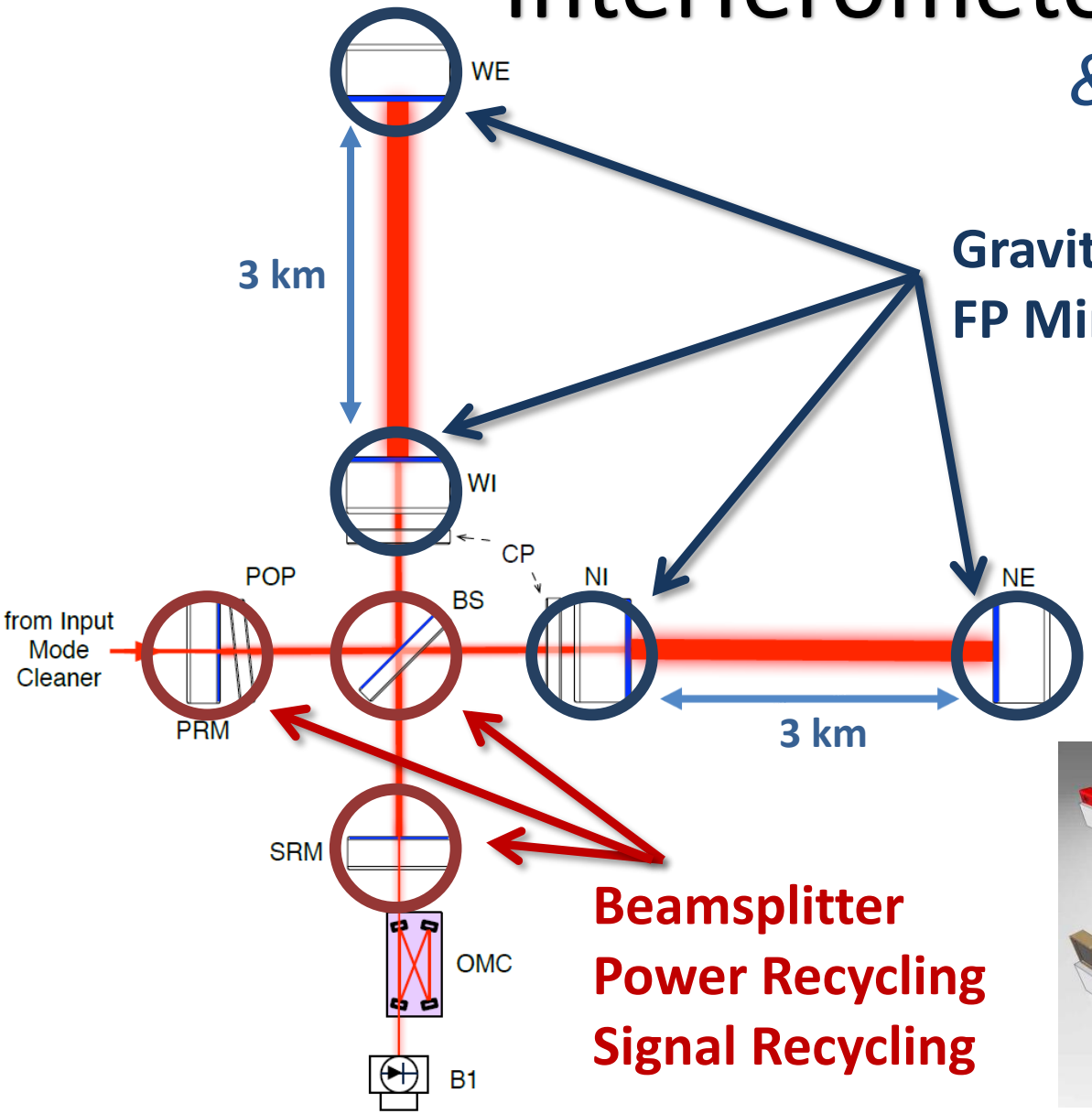
on behalf of the **Virgo Collaboration**

Overview

- **Advanced Virgo Payloads**
  - ITF test masses & sensitivity
  - Payload design
  - The *vacuum ghost*
  - O2 *Steel* Payloads vs O3 *Monolithic* Payloads
- **Payload characterization**
  - O3 mirror suspension Quality Factor
  - Q(f) & considerations
- **Sensitivity enhancement**
  - Mirror suspension thermal noise for O3
  - AdV sensitivity in O3 with monolithic suspension
  - Conclusions

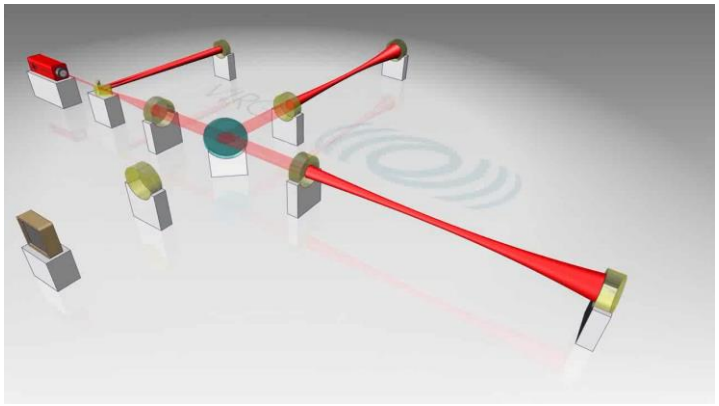
Interferometer test masses

& Sensitivity



Gravitational test masses:
FP Mirrors (Input & End)

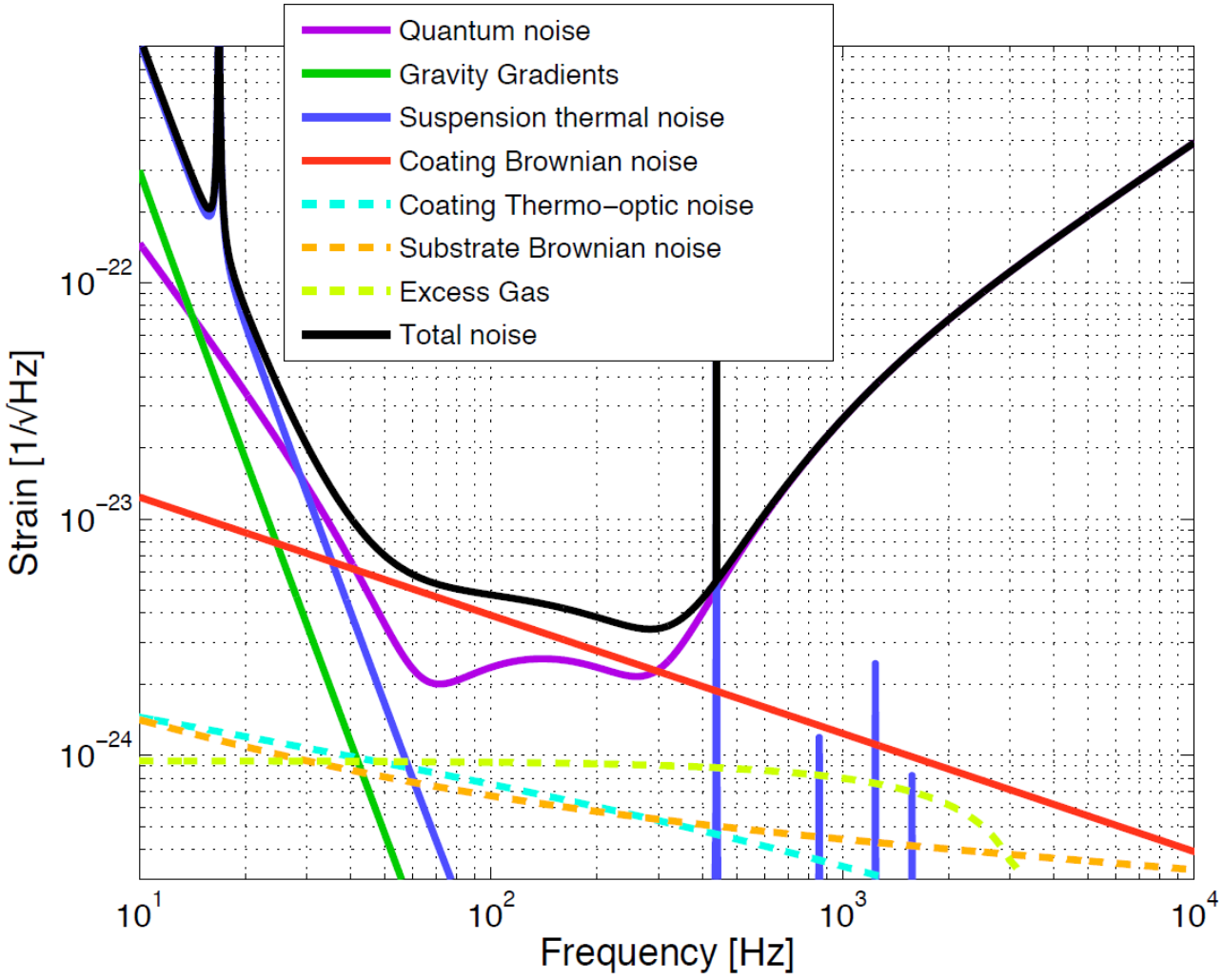
$$\delta L(\omega_{gw}) \approx \frac{1}{2} hL$$



Beamsplitter
Power Recycling
Signal Recycling

Interferometer test masses

& Sensitivity

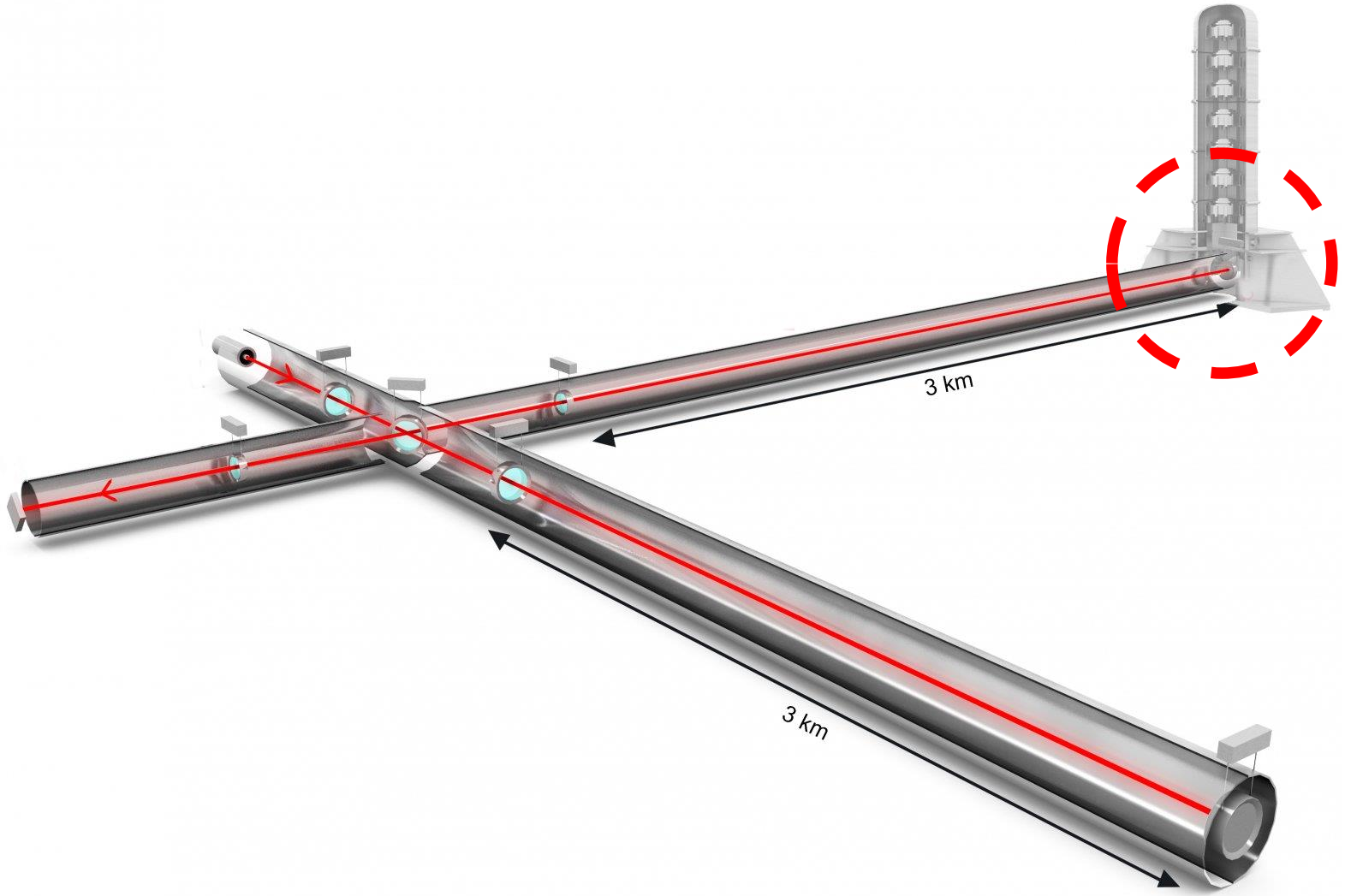


Test mass suspension:

- Seismic noise attenuation
- Suspension thermal noise

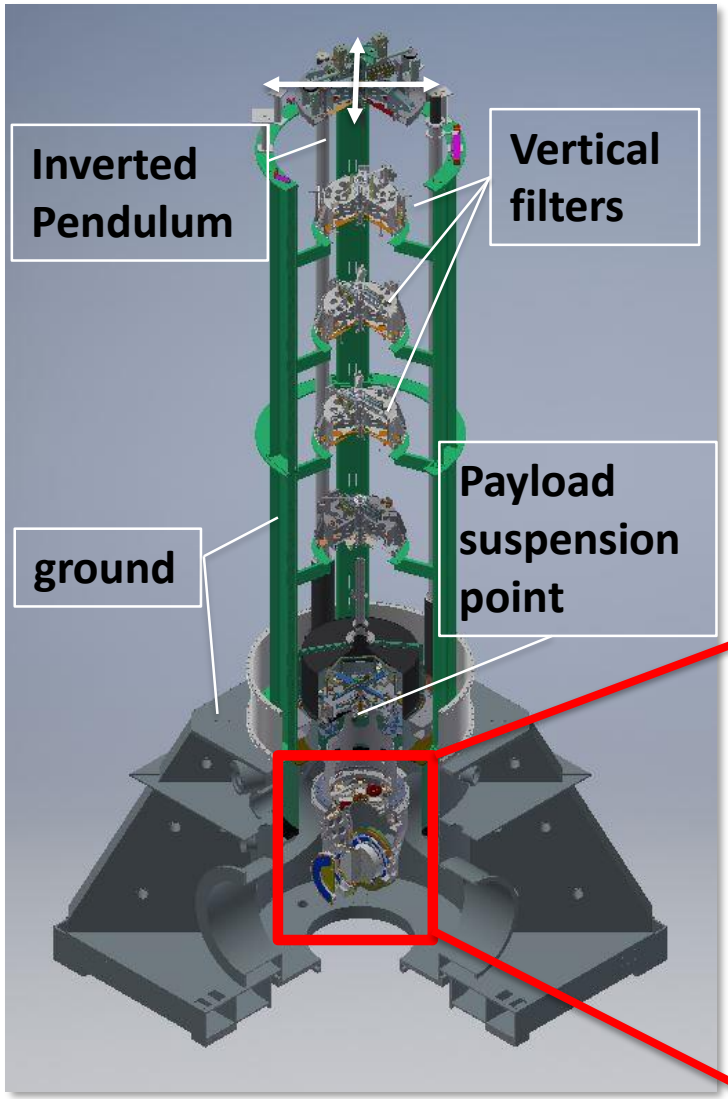
Interferometer test masses

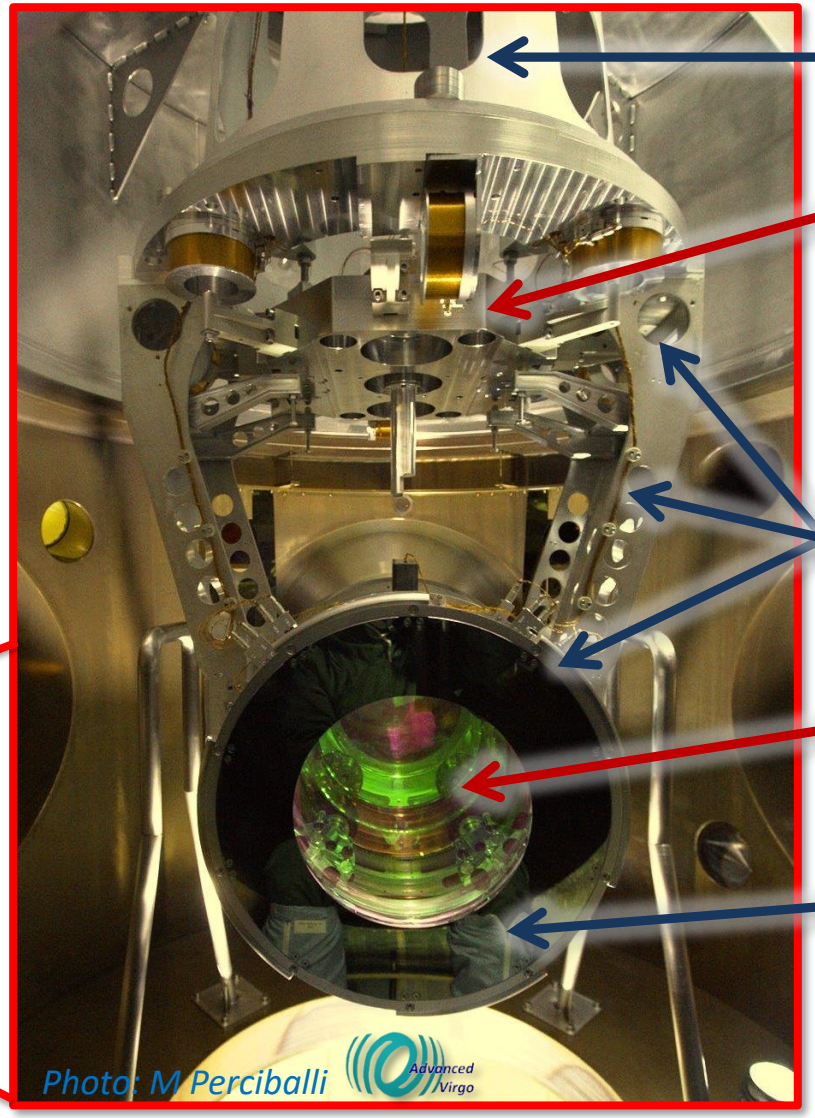
& Sensitivity



AdV Payloads

Payload Design

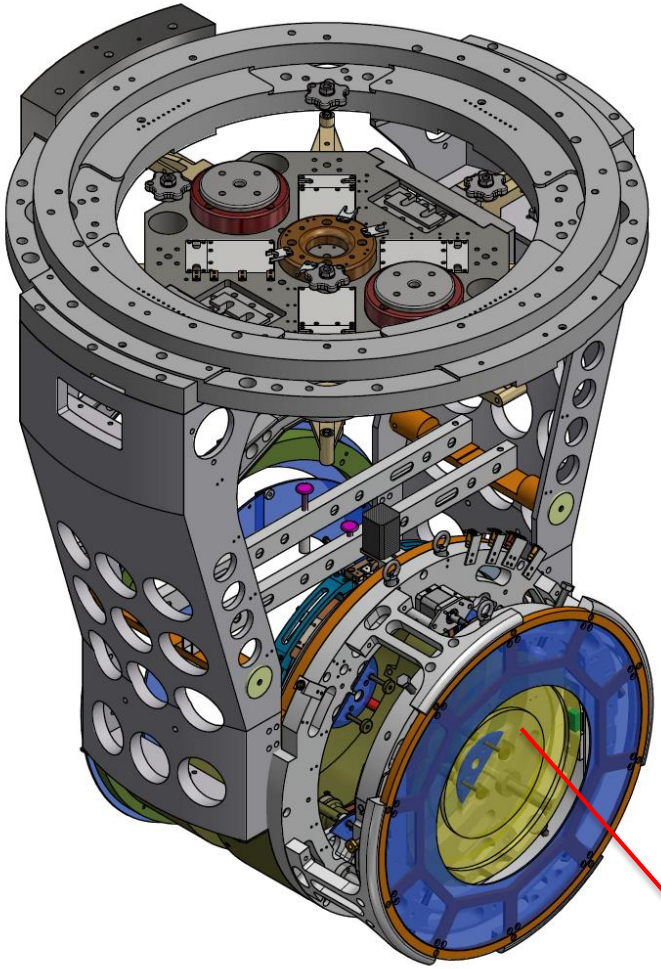




Payload Design

AdV Payloads

Input



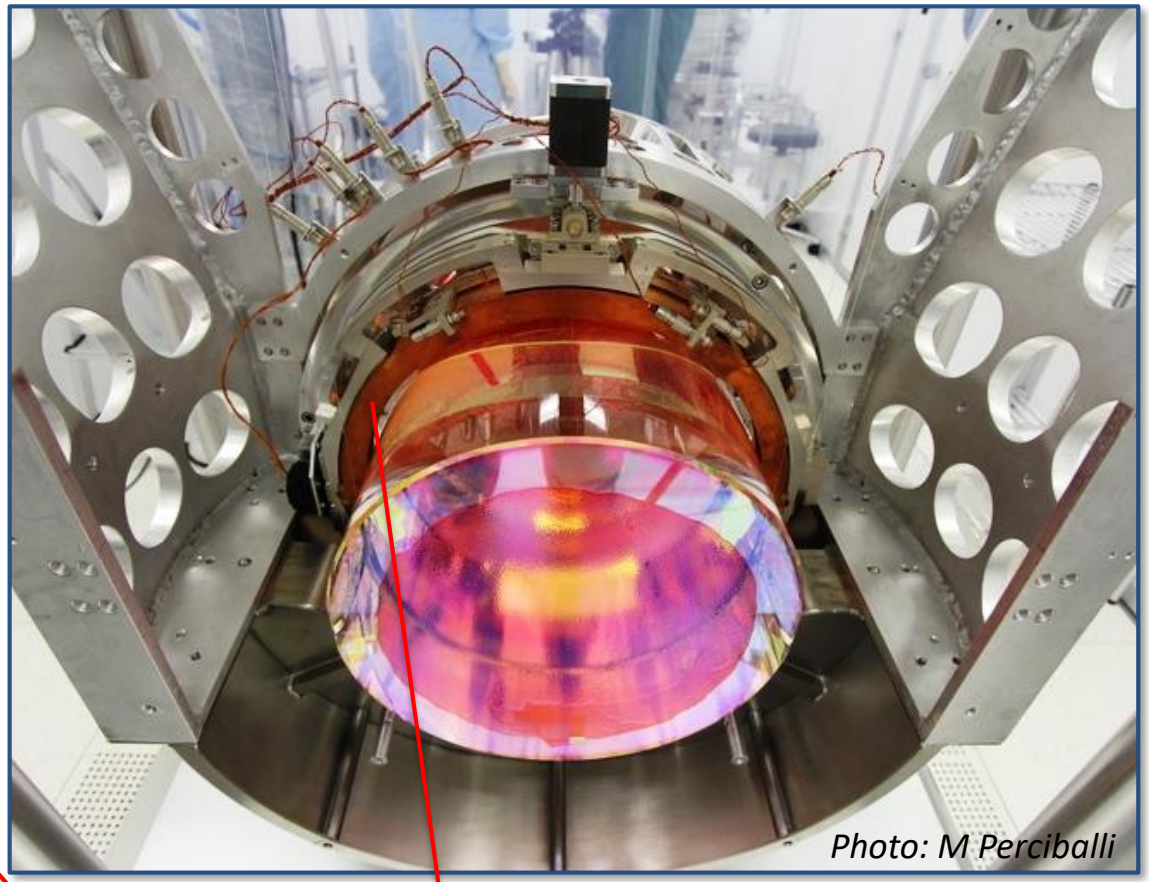
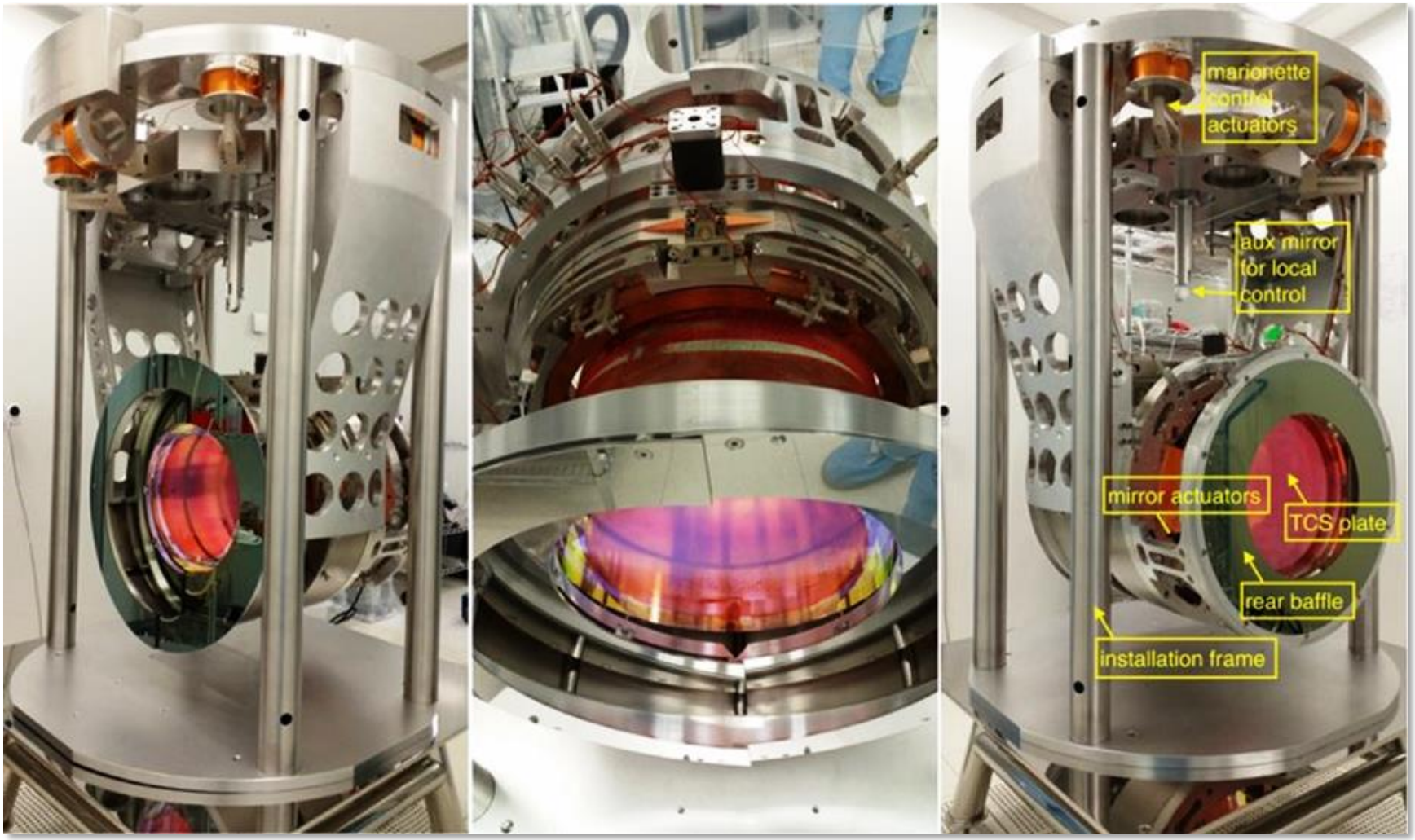


Photo: M Perciballi

TCS: thermal compensation
(Compensation Plate and Ring Heater)

Payload Design

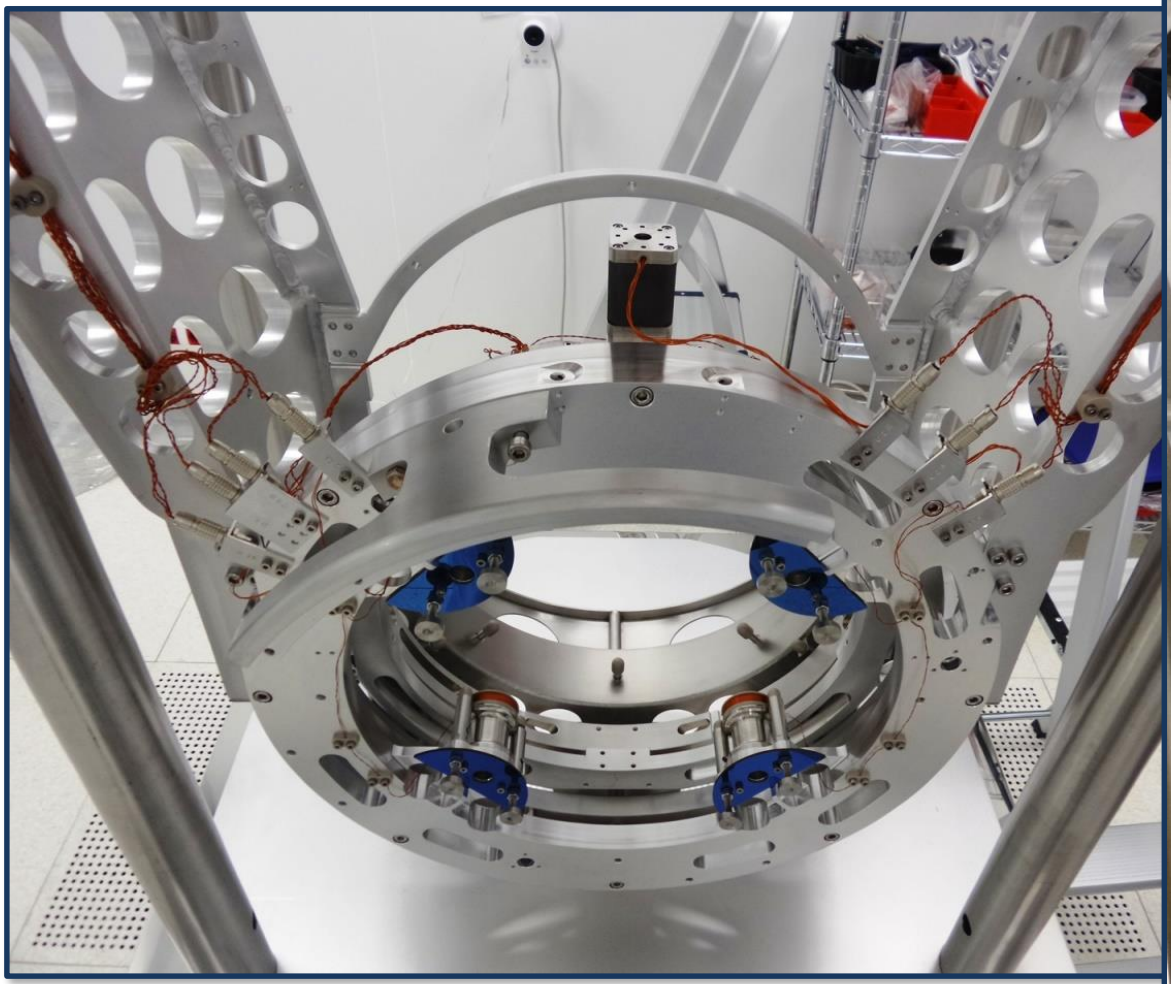
AdV Payloads
Input

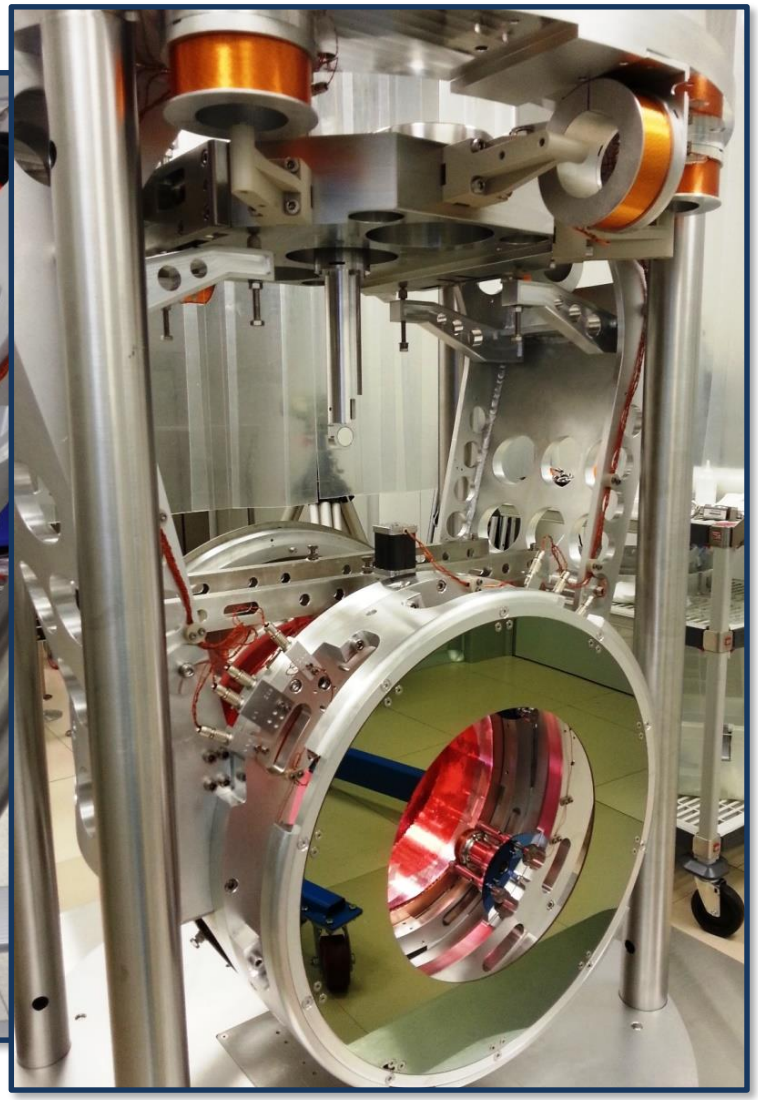


Payload Design

AdV Payloads

End

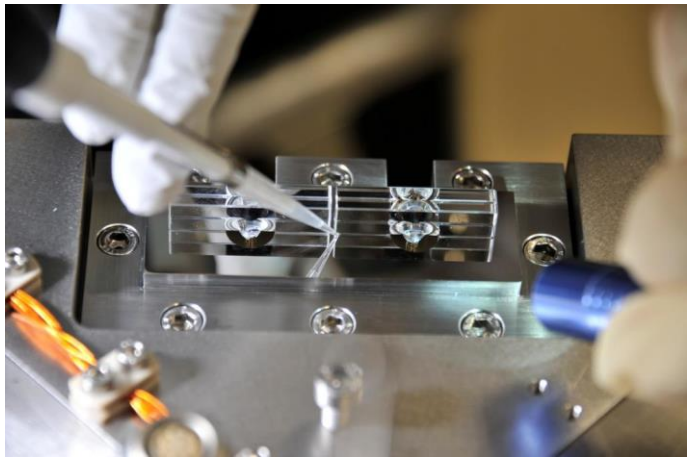


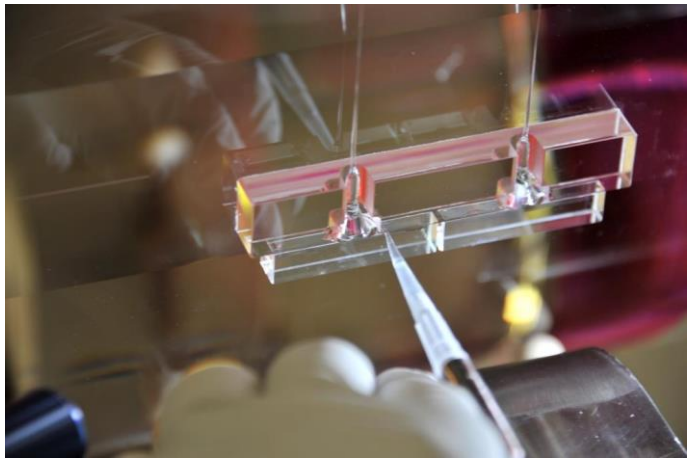


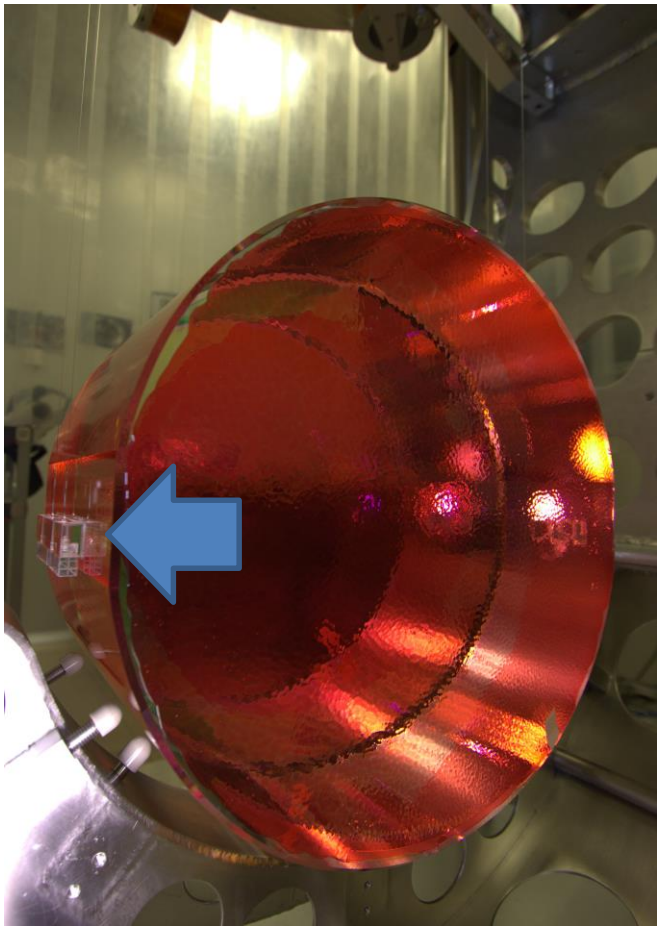
AdV Payloads

The "vacuum ghost"

AdV Payoads were designed to use the mirror monolithic suspension (MS) since the first observation run





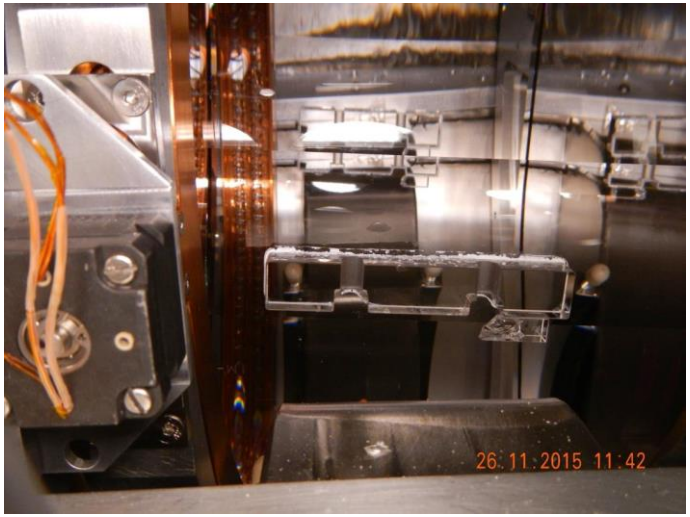


Payloads assembled and integrated without complications, but when the system was placed under vacuum…

AdV Payloads

The "vacuum ghost"

… MS failures of all the monolithic payloads!

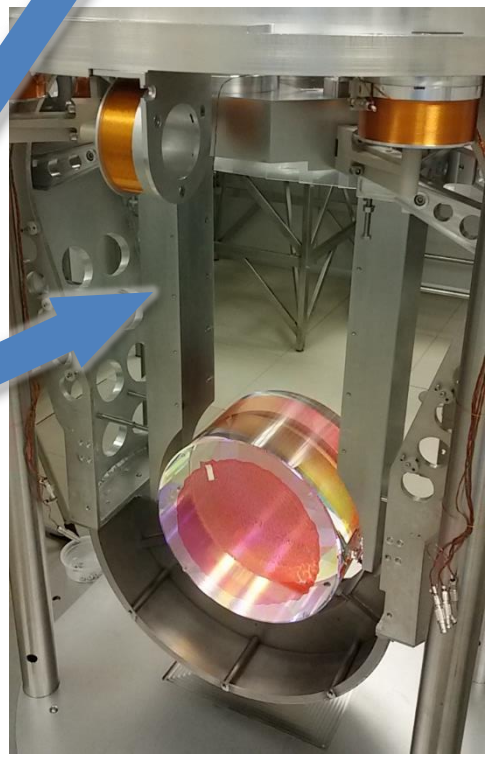


The collaboration studied all the possible breaking mechanisms:
mechanical, vacuum, thermal, chemical, radioactivity tests and so on…
(*VIR-0383A-16, VIR-0409A-17, …*)

Finally, the cause was identified and demonstrated to be the dust contamination of the vacuum pipes: failures always related to vacuum operations, starting on the venting tube side: *dust particles released by the scroll pumps hit the SiO_2 fibers with a possible velocity up to ≈20m/s : enough to damage their surface and break them*!

AdV Payloads

The "vacuum ghost"

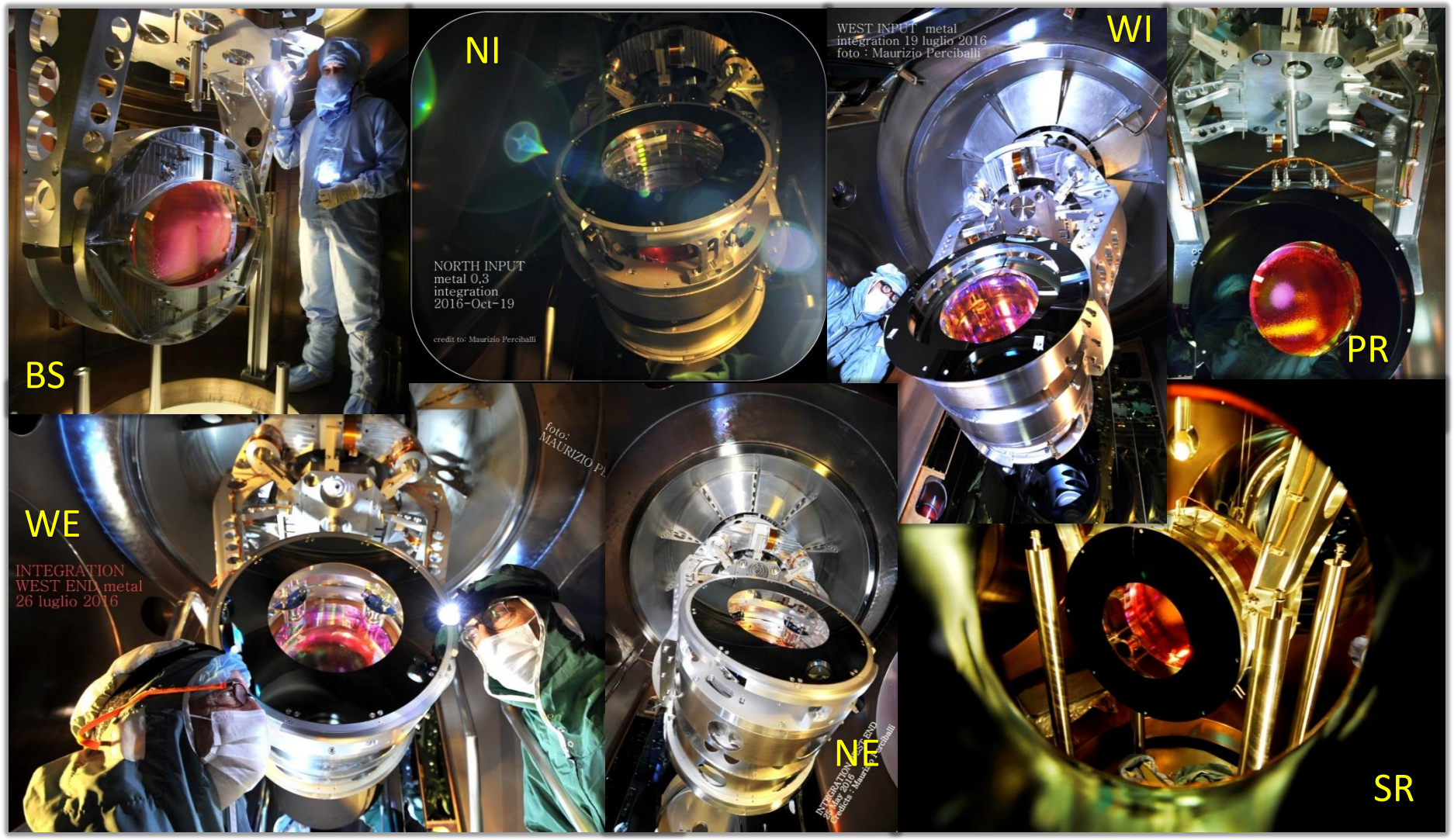


Reactions:

- Implementation of the **backup solution**: *steel-wire mirror suspension* to be ready for O2 (wise choice: GW170814 & GW170817)
- Upgrade and cleaning of the vacuum system and substitution of scroll pumps before O3
- Payload upgrade (safety fiber guards)
- Reintegration of Monolithic Payloads for O3

AdV Payloads

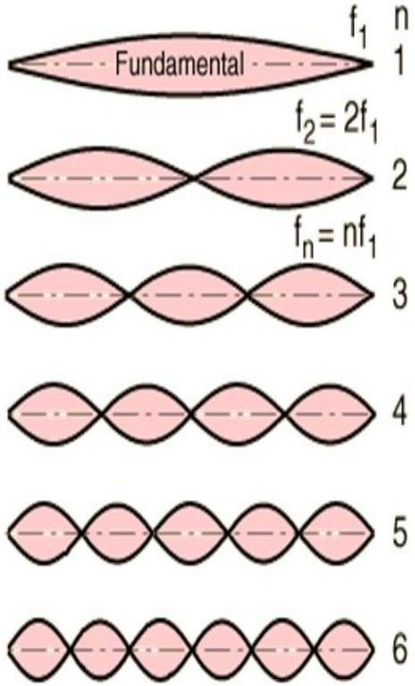
O2 "steel" payloads



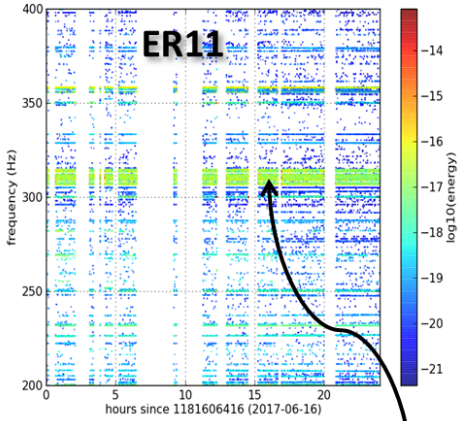
AdV Payloads

O2 "steel" payloads

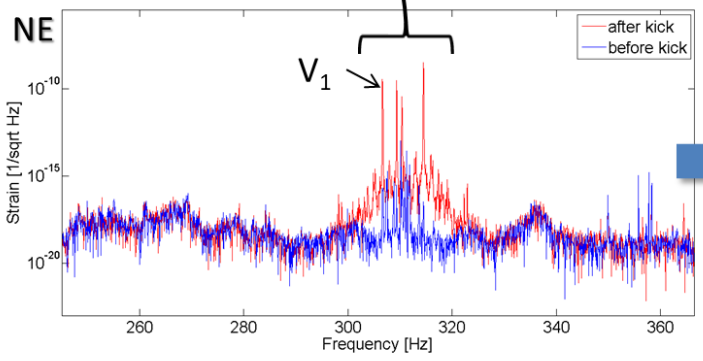
Violin modes' Q ⟺ Thermal Noise ➡ Sensitivity

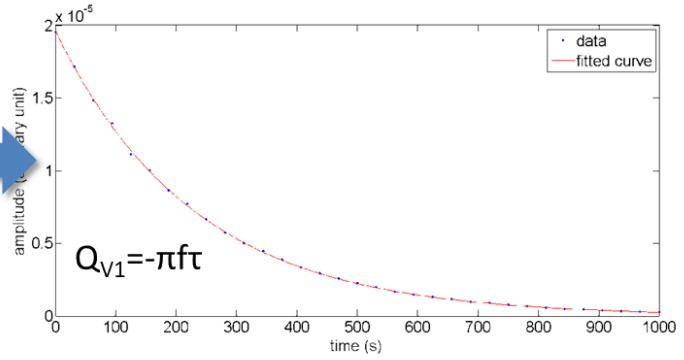


FP Payloads Q of steel-wire suspension



Violin Modes	FREQUENCY RANGE (Hz)	QUALITY FACTOR RANGE
NORTH INPUT	$306.7 \div 313.6$	$(2.18 \div 2.71) \times 10^5$
NORTH END	$306.6 \div 314.5$	$(2.21 \div 2.37) \times 10^5$
WEST INPUT	$307.3 \div 311.8$	$(2.03 \div 2.69) \times 10^5$
WEST END	$308.8 \div 311.7$	$(1.94 \div 2.92) \times 10^5$

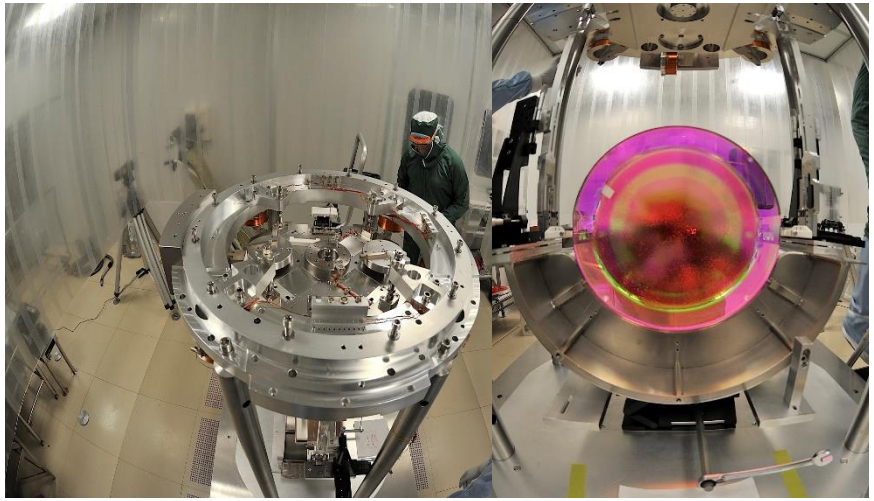




AdV Payloads

O3 "Monolithic" Payloads

Assembly and *Integration* procedures were standardized (VIR-0712A-17): safety and cleanliness improved, checklist and detailed documentation collected for each payload & mirror. Great accuracy in fiber production (Δl~0.1mm) and MS integration (~1mrad).



PAYLOAD	WEST INPUT
IN-TOWER CHECK ON	5 February 2018
EXTRACTED ON	5 February 2018
DISASSEMBLED ON	6 February 2018
ASSEMBLY STARTED ON	8 February 2018
ASSEMBLY COMPLETED ON	20 February 2018
INTEGRATED ON	21 February 2018
NOTE	Electrostatic charge measurments: - bottom vacuum chamber: -33V - Mirror HR: 0 ↔ -25V - M2 Mirror Column: -33V

Weight of removed steel clamps *Clamps, bolts, interfaces*	Sx: 1223g; Dx: 1223g TOT: 2446g
Weight of new anchors (x8):	8g each: TOT: 64g
Weight of λ/10 interfaces, bolts included:	1152g (#8), 1152g (#10), bolts included TOT: 2446 g
Weight of anchor carters (x2) *write if they were already mounted*	141g each TOT: 282 g
new Fiber Guards overall weight *(supports and bolts included)*	Sx: 1455 g Dx: 1446 g TOT: 2896
Weight change due to MS	
Weight change due to monolithic suspension instead of steel clamps *(indicate with sign increase/reduction)* **INCLUDE FIBER GUARDS**	-423 g (on +2473 g (on

If the marionette suspension wire is removed, write the dimension and weight of the spacer/washer	d (mm)	
	/	

1. PRELIMINARY INFORMATIONS *(in-tower balancing check)*

MARIONETTE AND CAGE BALANCING COUNTERWEIGHTS POSITION AND WEIGHT (in-tower check)

C,D,E,F,G,H,I,L,M NOT REMOVED FROM INTERFACE WITH F7!!

	(g)
A	2181
B	496
C	764
D	686
E	532
F	1298
G	1231
H	2181
I	147
L	143
M	
N	
O	
P	
Q	
R	
S	
T	
U	
V	
X	
Y	
Z	

TOTAL BALLAST F7 interface: 7654g

HF SIDE

H G F E D A B C

Not mounted

Not mounted

Not mounted

COUNTERWEIGHTS ON MARIONETTE ARMS (if present)

	(g)
HF	22
VFR	
HR	
VBR	
HB	
VBL	26

HF VFR VFL HR HR side

Note:
- removed all counterweights on peek arms: -138g
- removed aluminium marionette counterweights: -298g x2= -596
- added counterweights spacers: +72g
- removed steel wire clamping parts: -2446g
- added MS plates: +2304g
- added about 35g on VFL and VBL arms
  - **MS plates position:**

HR

INCLINATION OF THE EARS (08/02/2018)

Distance Ears – Wall: 8.55m // Distance Mirror – Laser: 0.3m (Me… made directly inside the clean hood with a portable laser bench)

EAR A

LASER

22mm => 1.3mrad - DOWNWARDS

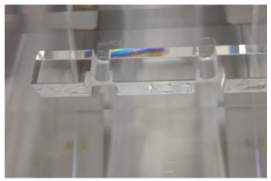
EAR B

8mm => 0.5mrad - UPWARDS

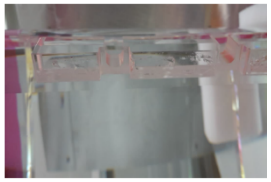
LASER

PICTURES OF EARS (08/02/18)

EAR A – Before cleaning process

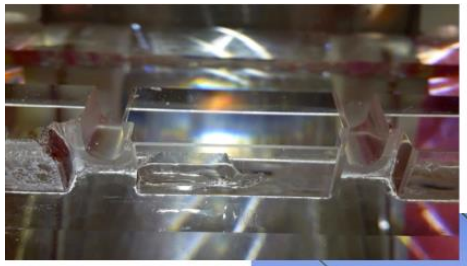


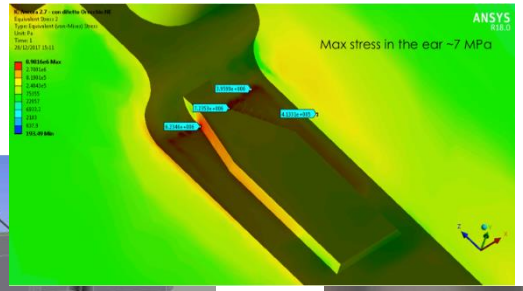
EAR A – After cleaning process

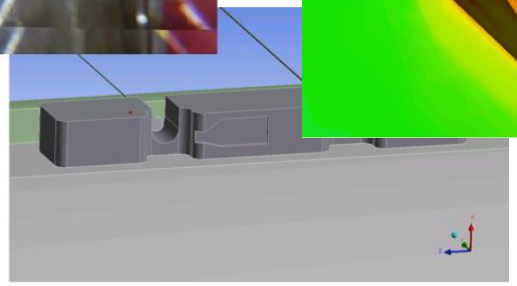


AdV Payloads

O3 "Monolithic" Payloads

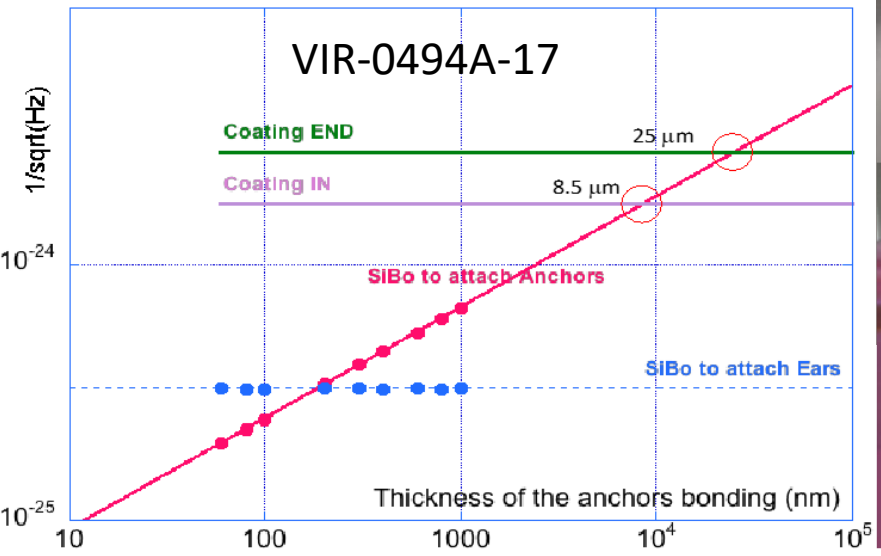






Damage relevance for thermal noise has been evaluated. Mirror ears cleaning before re-installation of MS

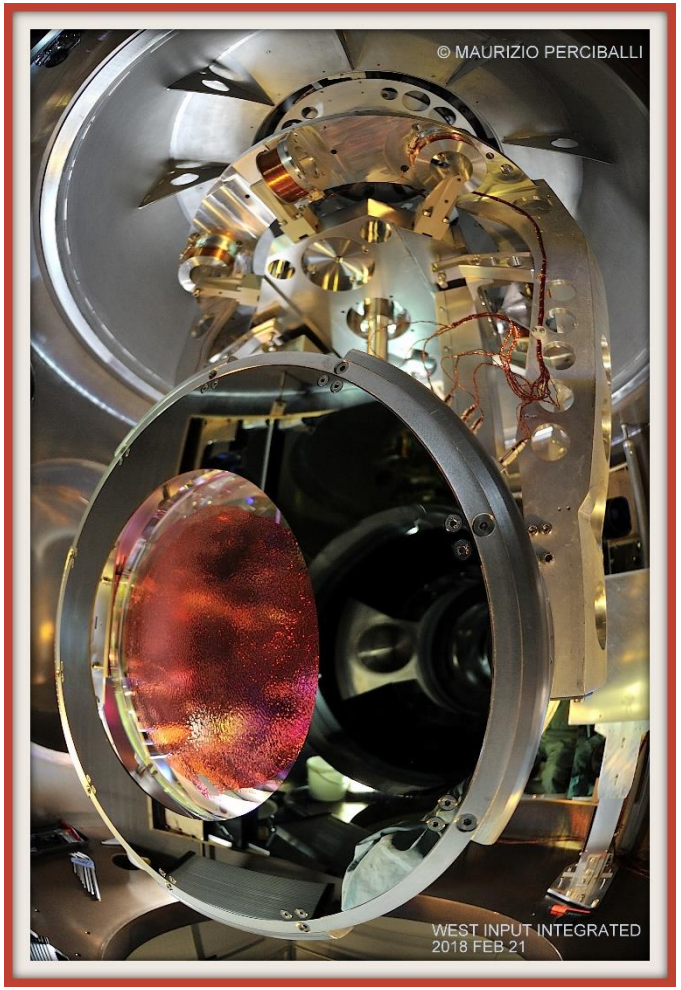
Thermal vs thickness



AdV Payloads

O3 "Monolithic" Payloads

PAYLOAD	EXTRACTION/ INTEGRATION	WEIGHT (kg)
North End	2017/11 28th 2017/12 20th	145,7
North Input	2017/12 14th 2018/01 09th	145,5
West Input	2018/02 05th 2018/02 21st	147,9
West End	2018/02 07th 2018/03 06th	146,4



Overall load on the last steering filter recovered.

Strong commitment, great teamwork (Virgo collaboration & EGO staff), prompt accident recovery.

Payload Characterization

O3 Payloads: Mirror suspension Quality Factor

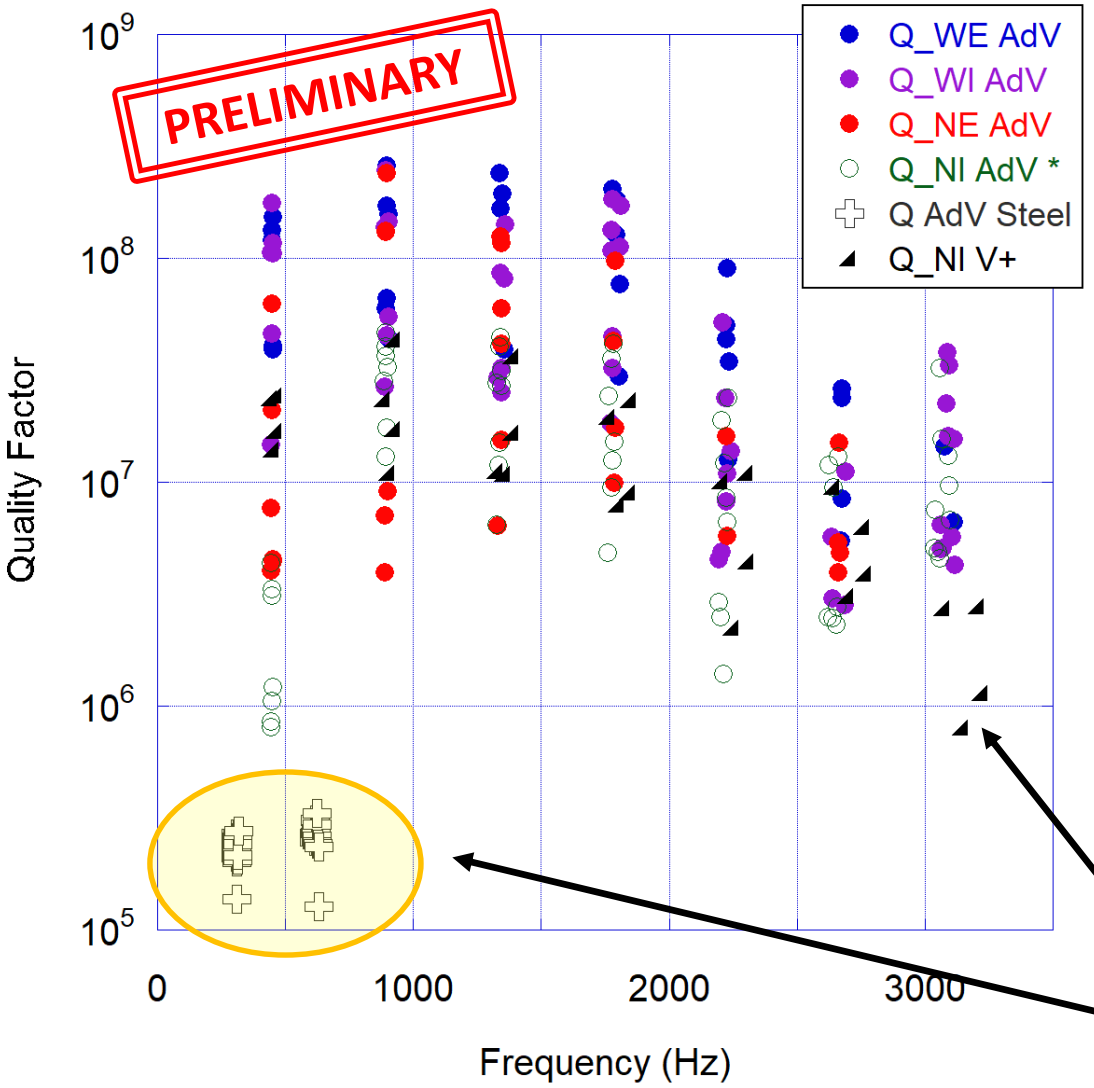
TM	Monolithic Suspension for O3	Steel Suspension (O2)
	2nd Violin Q	2nd Violin Q
WE	$5.9 \times 10^7 - 2.59 \times 10^8$	$(5.28 - 5.86) \times 10^5$
WI	$2.66 \times 10^7 - 2.47 \times 10^8$	$(4.07 - 5.39) \times 10^5$
NE	$3.95 \times 10^6 - 2.40 \times 10^8$	$(5.04 - 7.27) \times 10^5$
NI*	$1.29 \times 10^7 - 4.6 \times 10^7$	$(5.34 - 8.07) \times 10^5$

PRELIMINARY

**: measured during the short commissioning run in the intermediate configuration (North arm monolithic, West arm steel)*

Payload Characterization

O3 Payloads: Mirror suspension Quality Factor



$$Q(\omega_0) = \frac{1}{\phi(\omega_0)}$$

- Q(f) behavior likely related to marionette bulk resonances and to the anchor/marionette interfaces
- Low/High Q splitting probably related to losses along the anchor/ear direction

→ *FEM analysis in progress!*

** Measured in the intermediate configuration (North-arm monolithic, West-arm steel)*

Virgo+ monolithic suspension with old clamping system

Steel wire suspension in O2

Payload Characterization

O3 Payloads: Mirror suspension Quality Factor

- Comparing Q(f) with FEM analysis, assuming losses due only to fused silica fibers, we estimated that the loss angle ϕ is:
  - about a factor 30 worst than the nominal value for SiO_2 in North ITM and ETM
  - about a factor 5 worst than the nominal value for SiO_2 in West ITM and EMT

(VIR-0305A-18)

PRELIMINARY

Possible explanations:

- Control loops of the other TM affect the ringdown? ($Q_{meas} < Q_{real}$?)
- Higher losses on recovered mirror ears?
- Recoil losses from payload suspension?

Will be clarified with further violin measurements + *test payload* measurements

Sensitivity Enhancement

Mirror suspension thermal noise for O3

Thermal noise: Fluctuation Dissipation Theorem

$$S_X^{FDT}(\omega) = \frac{4k_bT}{m\omega} \frac{\omega_0^2\phi(\omega)}{(\omega^2-\omega_0^2)^2 + [\omega_0^2\phi(\omega)]^2}$$

Violin Quality factor measurements ➡ loss angle evaluation

$$Q(\omega) = \frac{\omega}{\omega_0\phi(\omega)}$$

$$\begin{cases} \phi_n(\omega) = \phi_w(\omega)\frac{2}{k_e l}\left(1+\frac{n^2\pi^2}{2k_e l}\right) \\ \phi_w(\omega) = \phi_{str}(\omega) + \phi_{sur}(\omega) + \phi_{thermoel}(\omega) \end{cases}$$

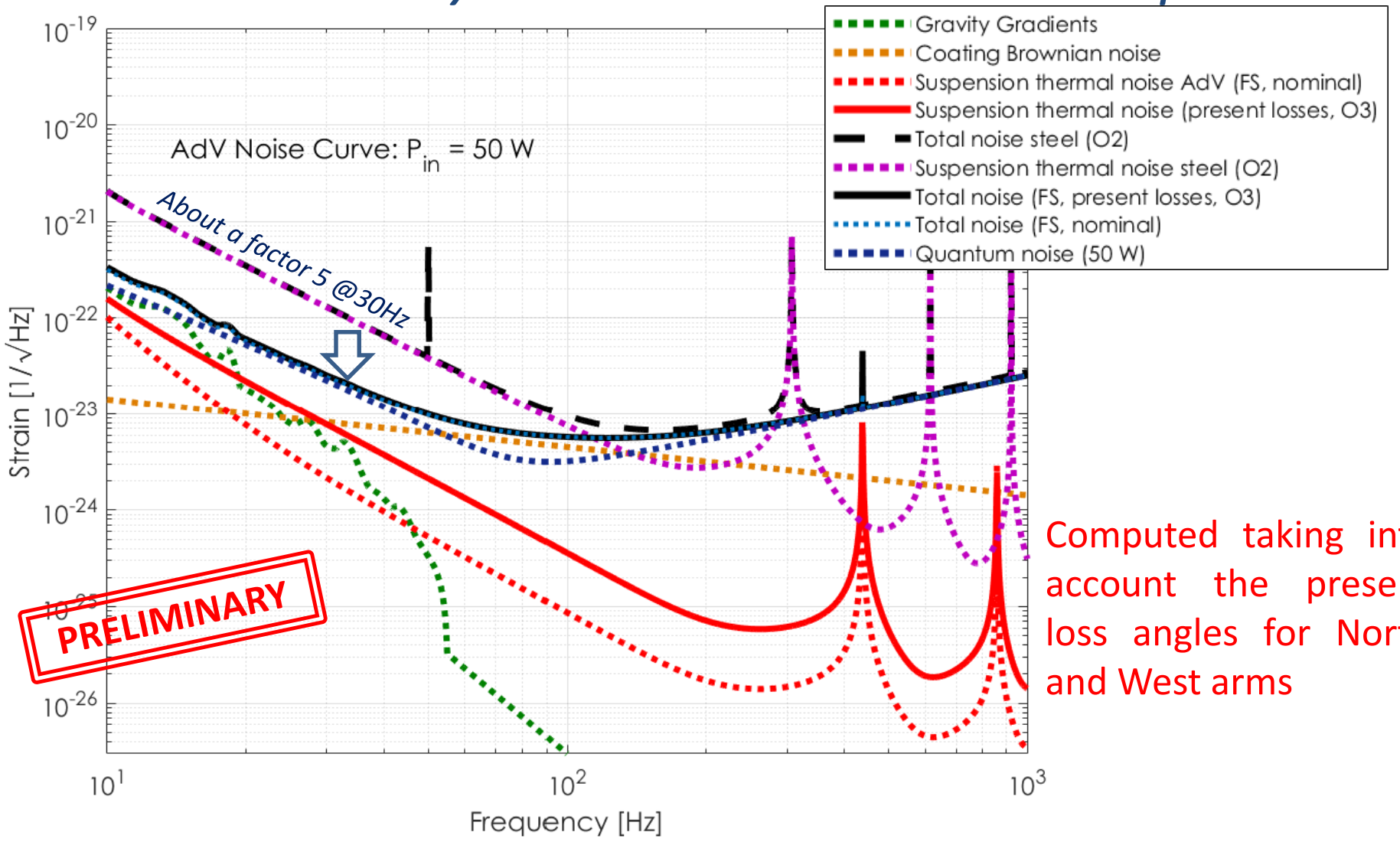
Violin thermal noise:

$$S_{viol}(\omega) = \frac{8k_BT\rho_l l}{\pi^2 m^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\frac{\omega_n^2}{\omega[(\omega_n^2-\omega^2)^2+\phi_n^2(\omega)\omega_n^4]}\phi_n(\omega)$$

Φ evaluation ➡ analithical thermal noise & sensitivity computation

Sensitivity Enhancement

AdV sensitivity in O3 with monolithic suspension



Computed taking into account the present loss angles for North and West arms

Conclusions

- AdV Payloads for O3 reintegrated adopting the original monolithic suspension;

- Upgrade of vacuum system and payload to avoid any SiO_2 fiber breaking due to dust contamination;

- TM suspension losses greater than nominal values for SiO_2;

- TM suspension losses reduced WRT those of steel wire suspension (O2 configuration): possible enhancement of the LF sensitivity up to a factor ~5.

- West arm TMs show the improvement of the suspension *Q* introduced by the new upper interface with the marionette WRT that used in Virgo+. North arm TM lower *Q*s will be further investigated and fixed.

Thank you for your attention!