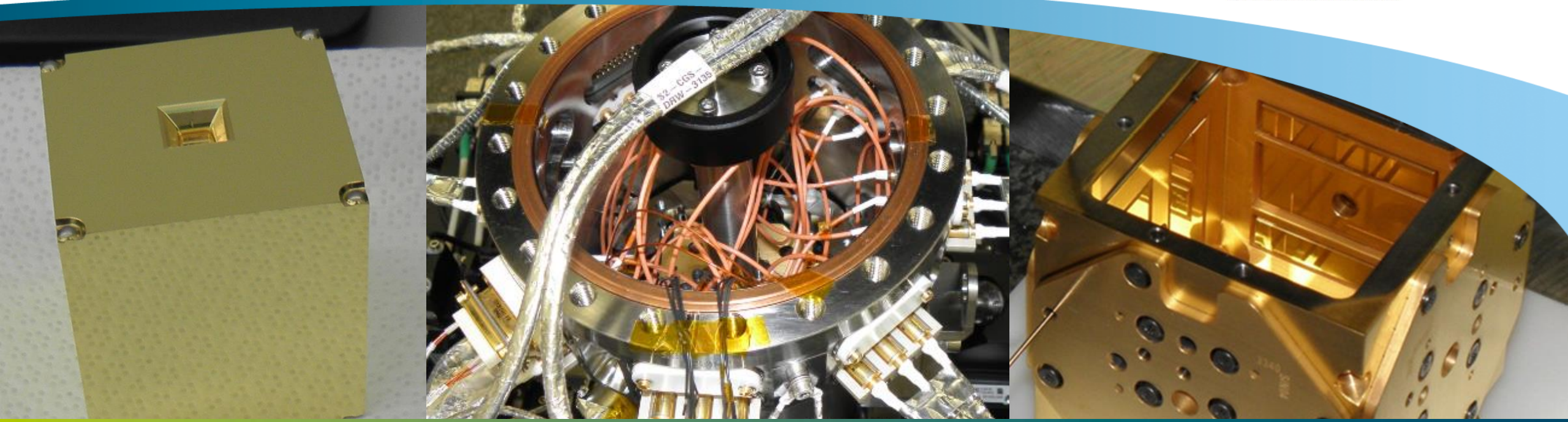
Dec 4th 2025, Paolo Sarra

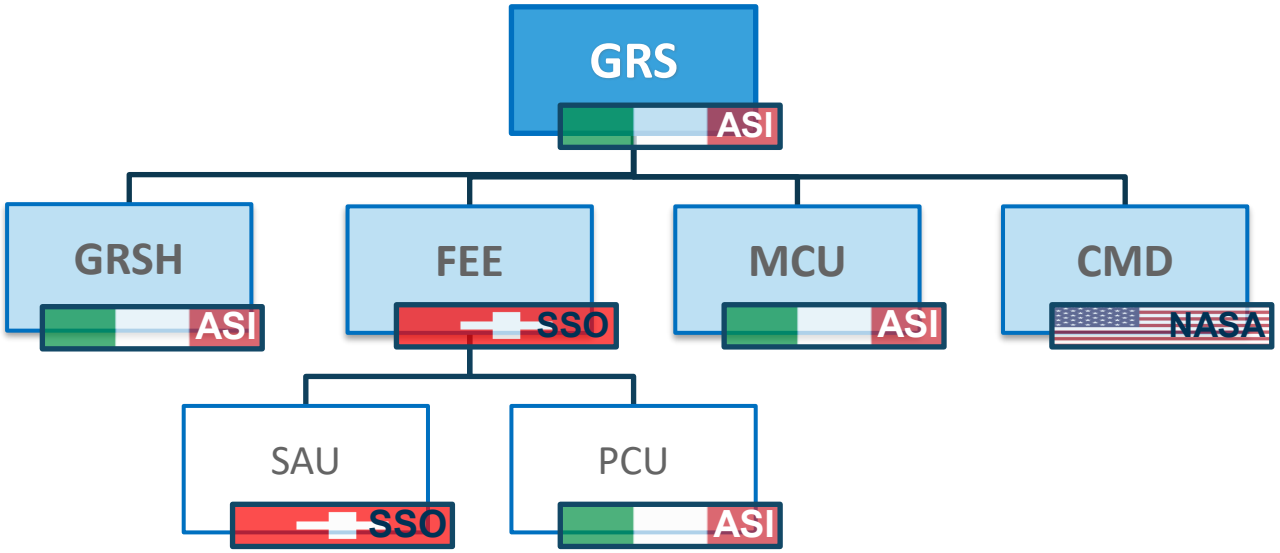


SPACE SYSTEMS

The heritage of LISA Pathfinder for the development of the Gravitational Reference System for LISA

OHB Italia: from LPF to LISA

- OHB Italia provided support to GRS PI Team in the design, development, and verification of the LPF Gravitational Reference System (aka Inertial Sensor System)
- For LISA the GRS Italian contribution is further extended:
  - → GRS Head full unit including mechanisms
  - → Mechanism Control Unit (MCU)
  - → Power Conditioning Unit (PCU) of the GRS Front End Electronics (FEE)



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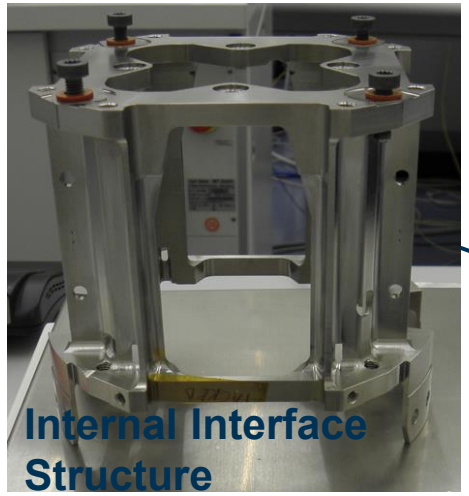
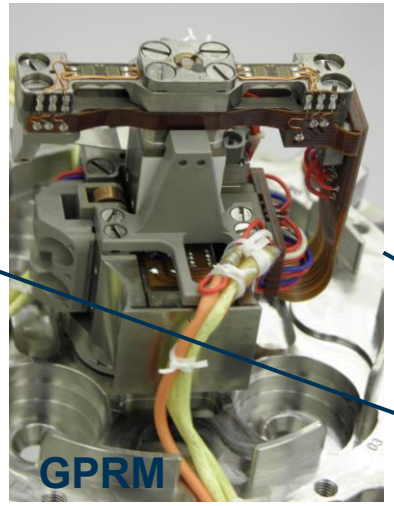
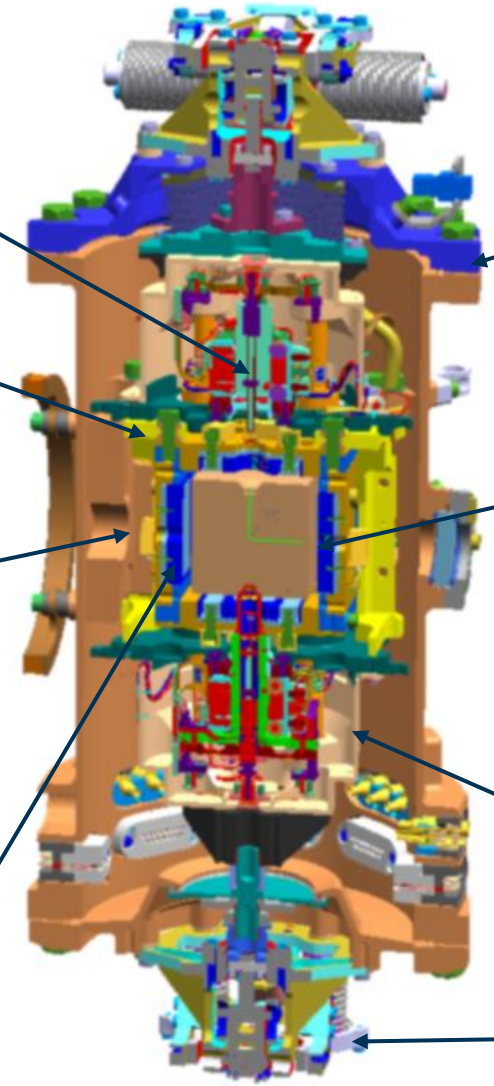
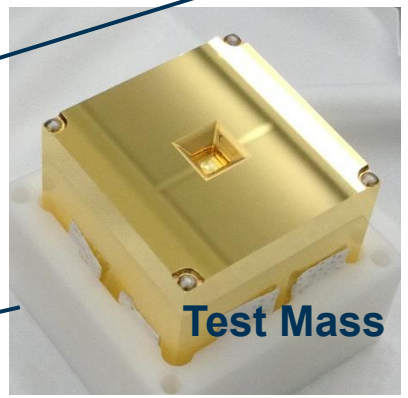
LPF Inertial Sensor Head Design


Internal Interface Structure


GPRM

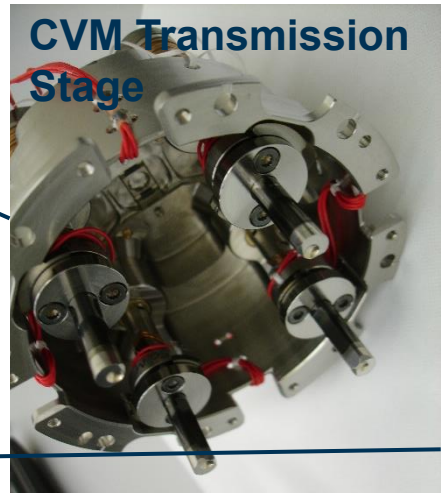


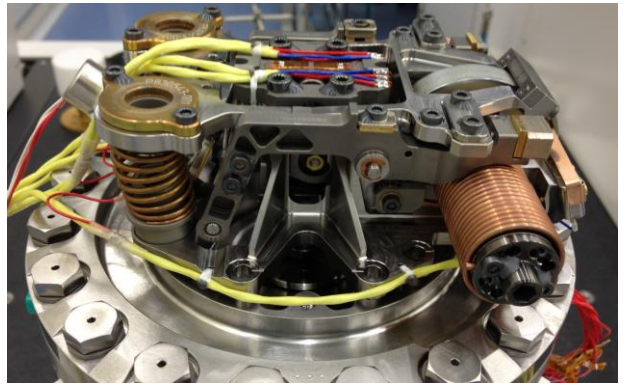

Test Mass


Vacuum Chamber


Internal Balance Mass


Electrodes Housing


CVM Transmission Stage


CVM Actuator Block

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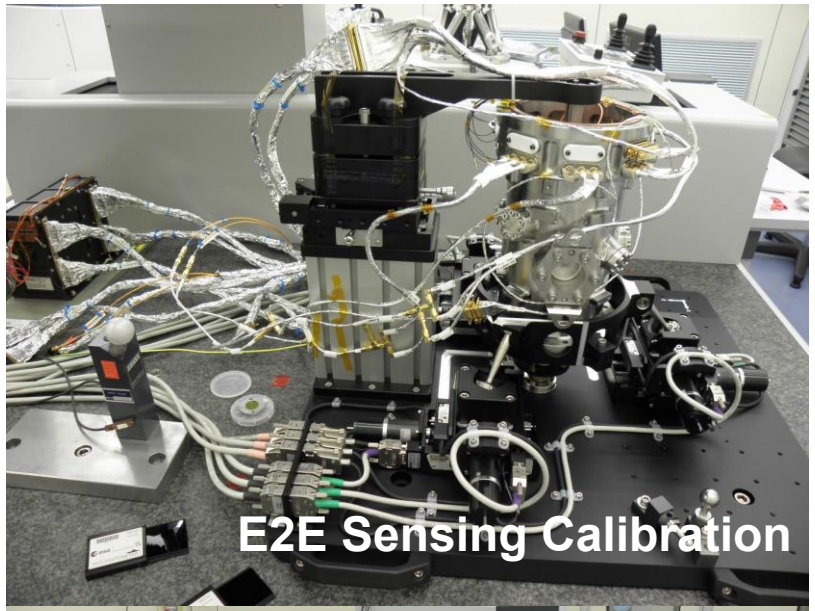
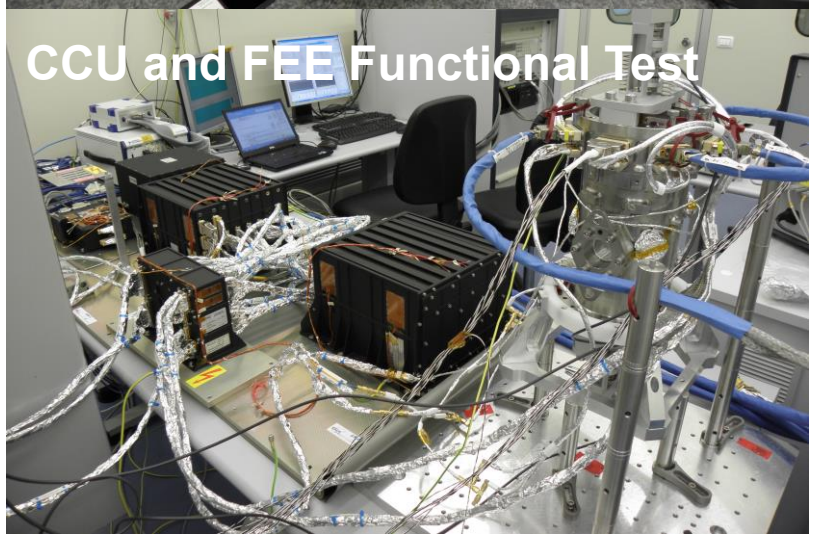
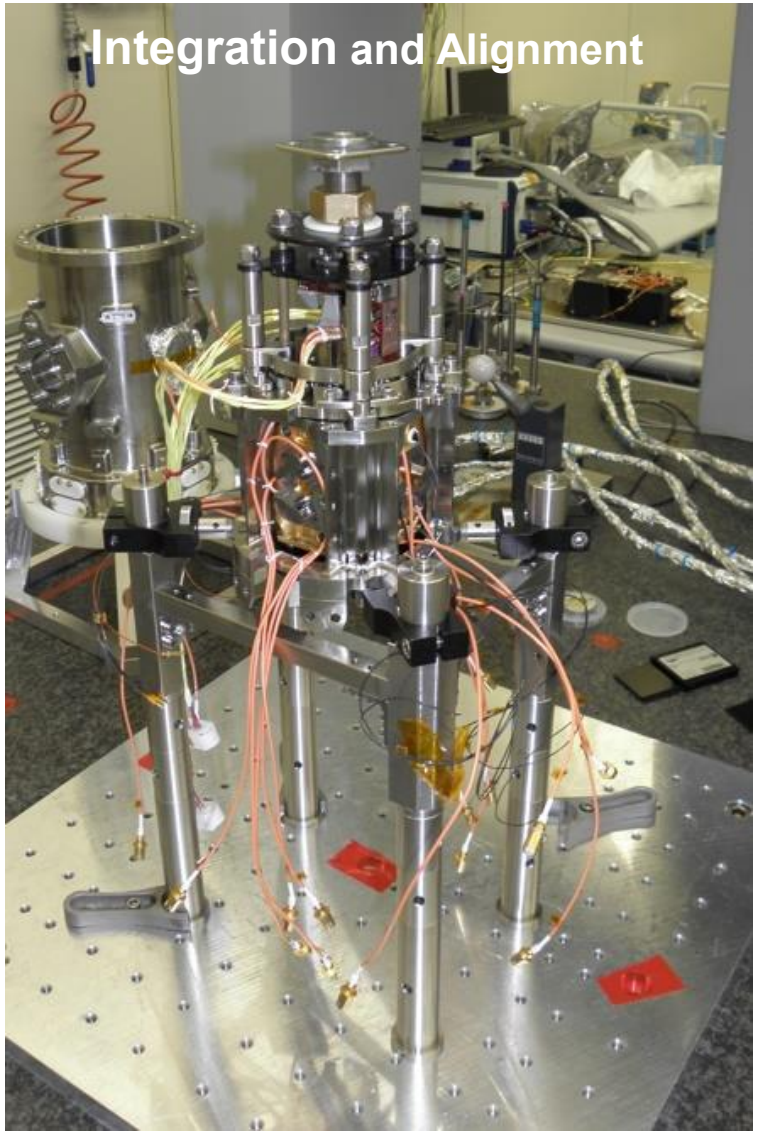
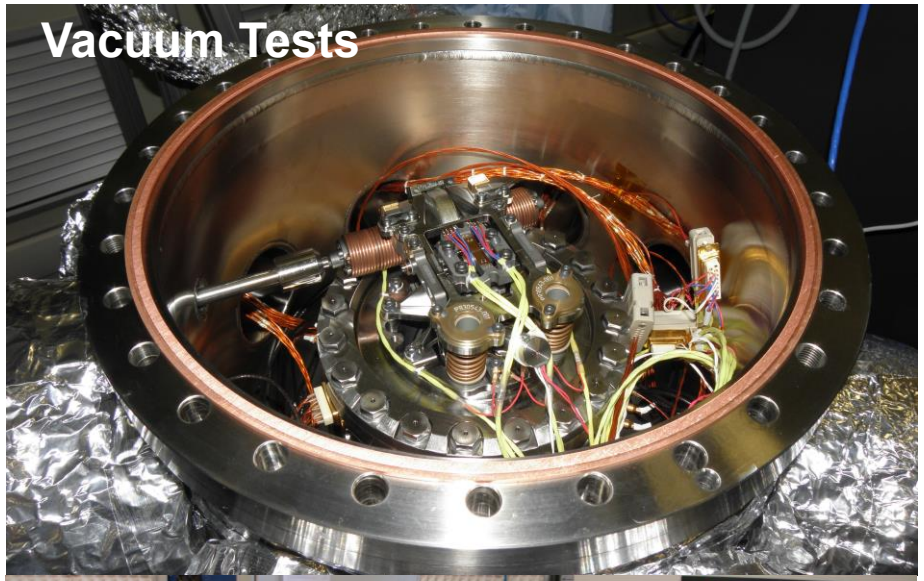
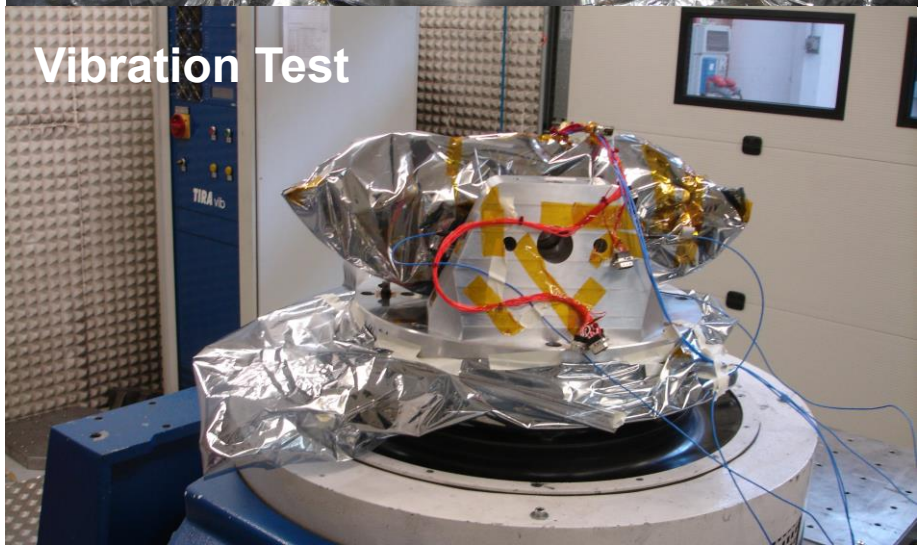
LPF Inertial Sensor Integration and Tests at OHBI











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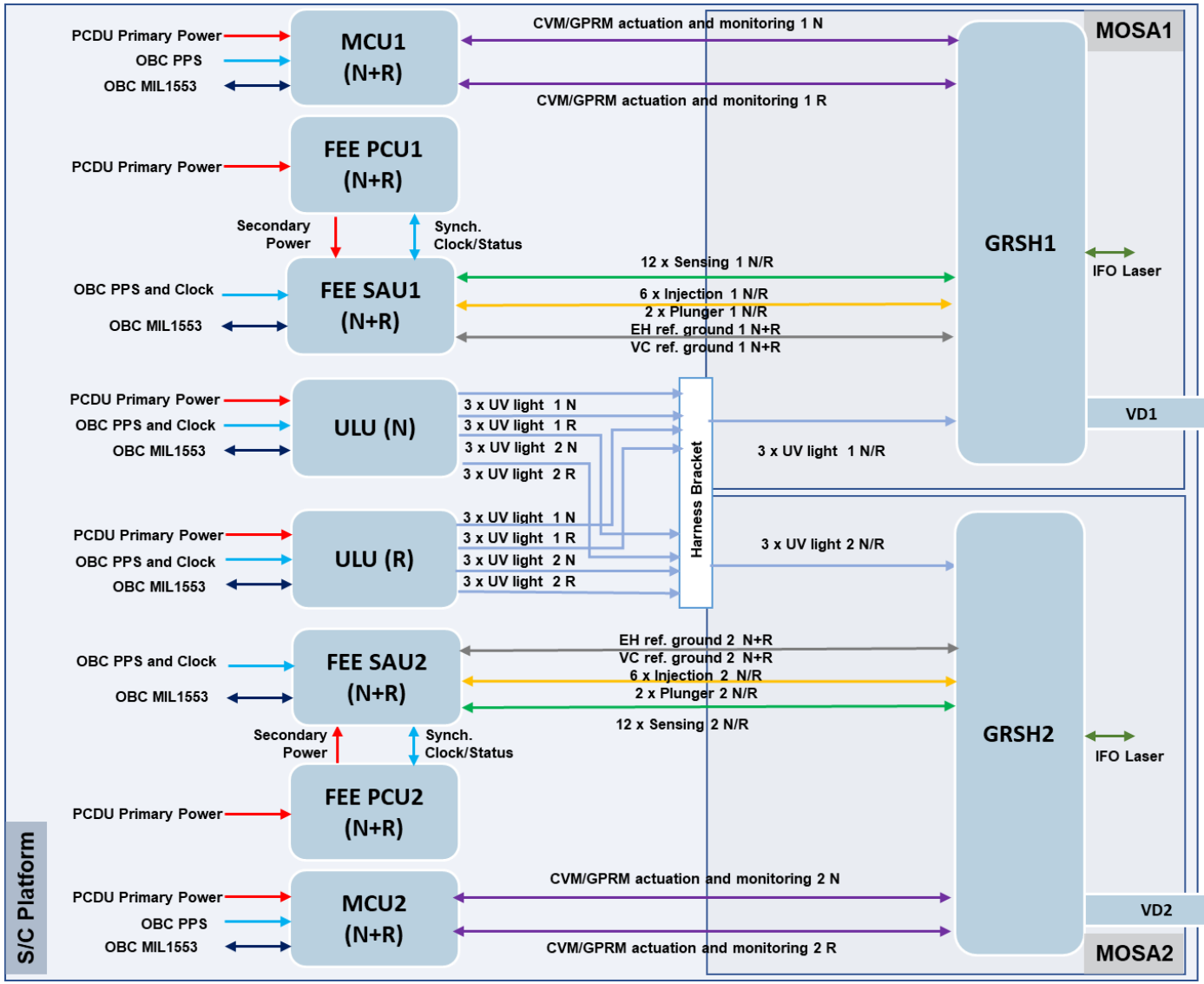
GRS: what to adapt for LISA

- The successful LPF mission has demonstrated that the LPF GRS design is mature for LISA mission.
- However, a full re-build of the LPF GRS units is not compatible for LISA.
- Design modifications are necessary to comply with the specific LISA mission requirements, such as the longest on-ground storage and mission duration, and to be compatible with LISA MOSA and S/C.
- GRS maintain the same LPF architecture, but:

  → ULU implements LEDs technology replacing Hg Lamps

  → FEE inherits high-performance capacitive sensing with increased electrostatic actuation

  → MCU combine in a single unit both mechanisms drivers with improved TM release control



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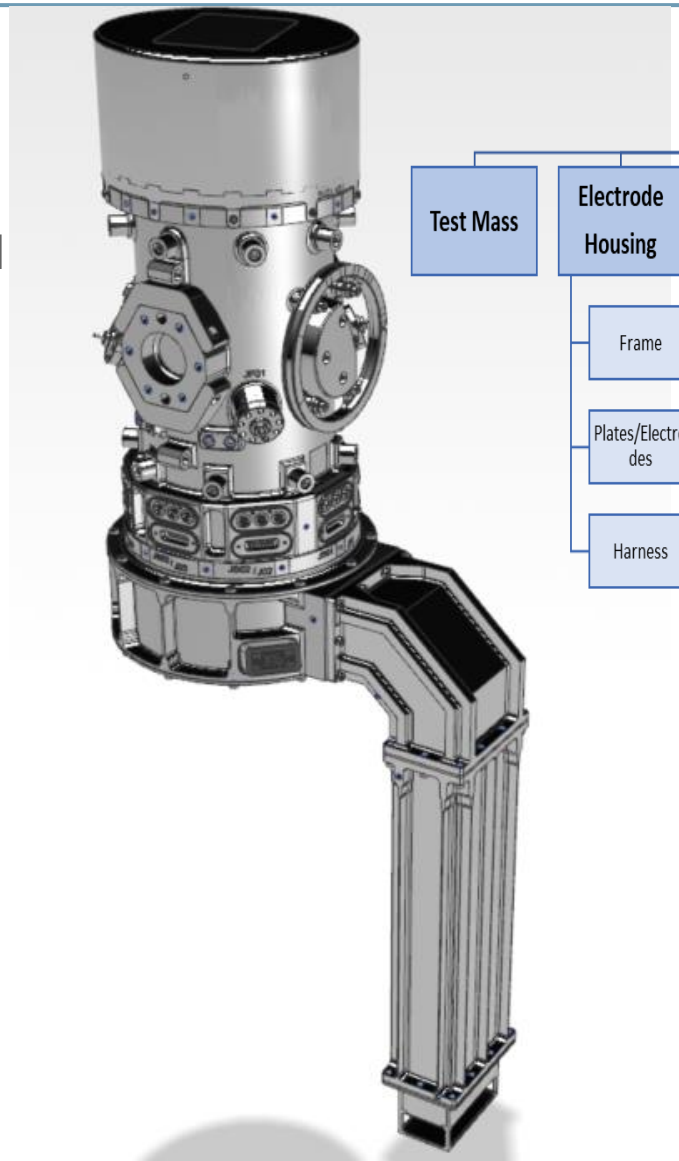
GRS Head: what to adapt and improve for LISA

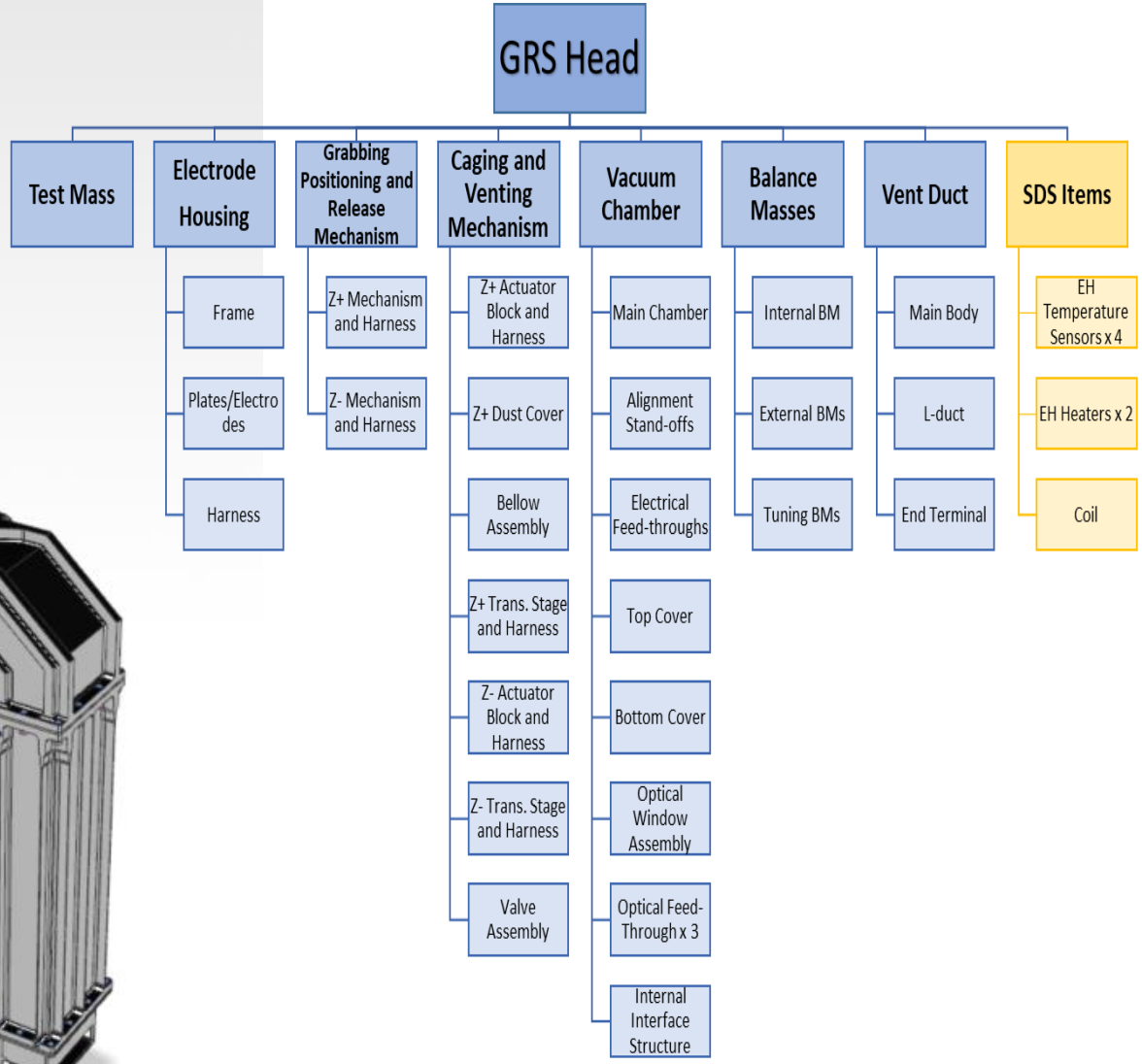
- GRSH design largely inherited by LPF
- Main design upgrade wrt LPF:

→ **Vacuum:** hermetic and hard mounted VD to GRSH VC, on ground static vacuum minimizing water permeation through VV to preserve GRSH internal outgassing rate,

→ **Self-gravity:** implementation of a new balance masses kit, optimized to new requirements,

→ **TM release:** design upgrade of GPRM, in parallel investigated to implement a more robust release also in consideration of an autonomous operation





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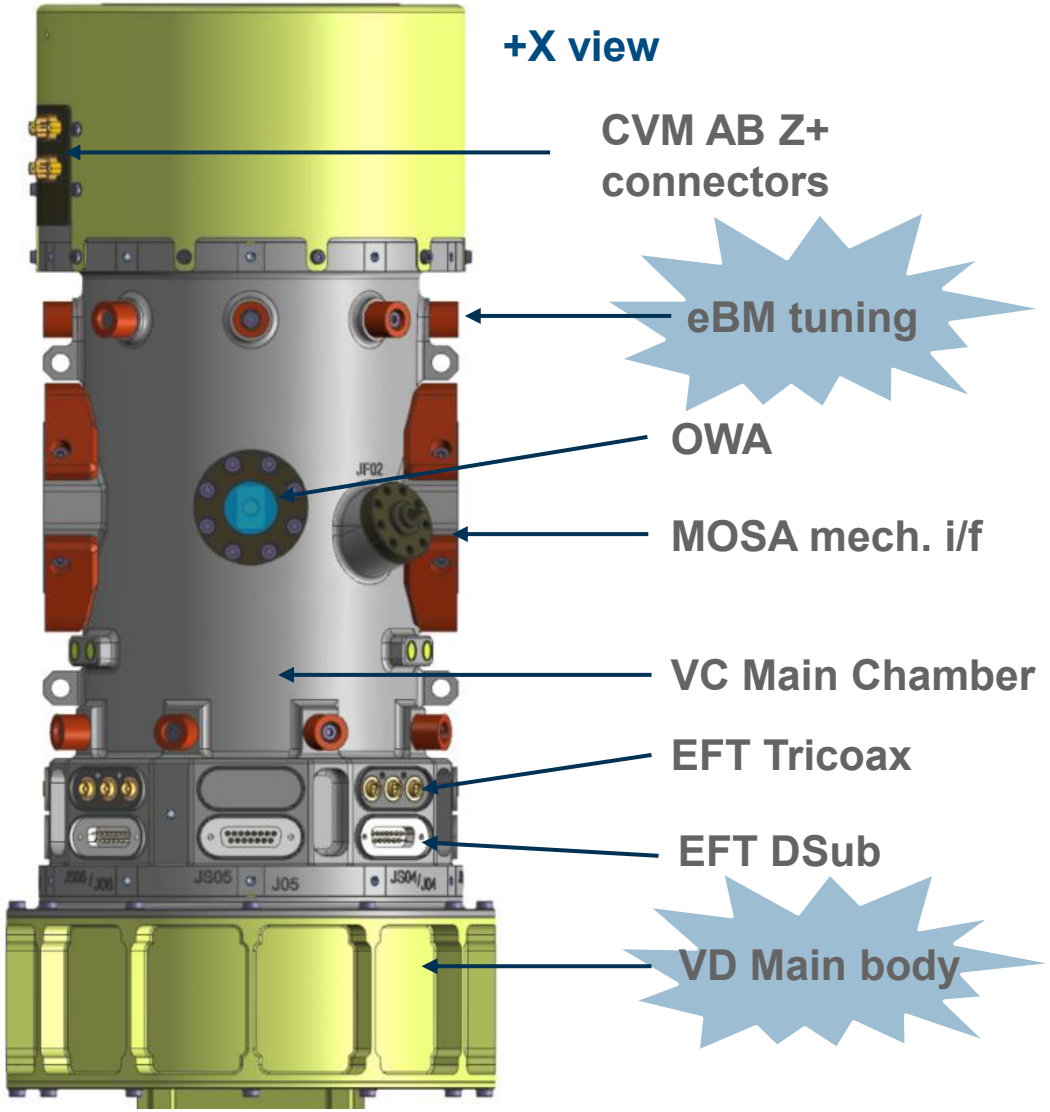
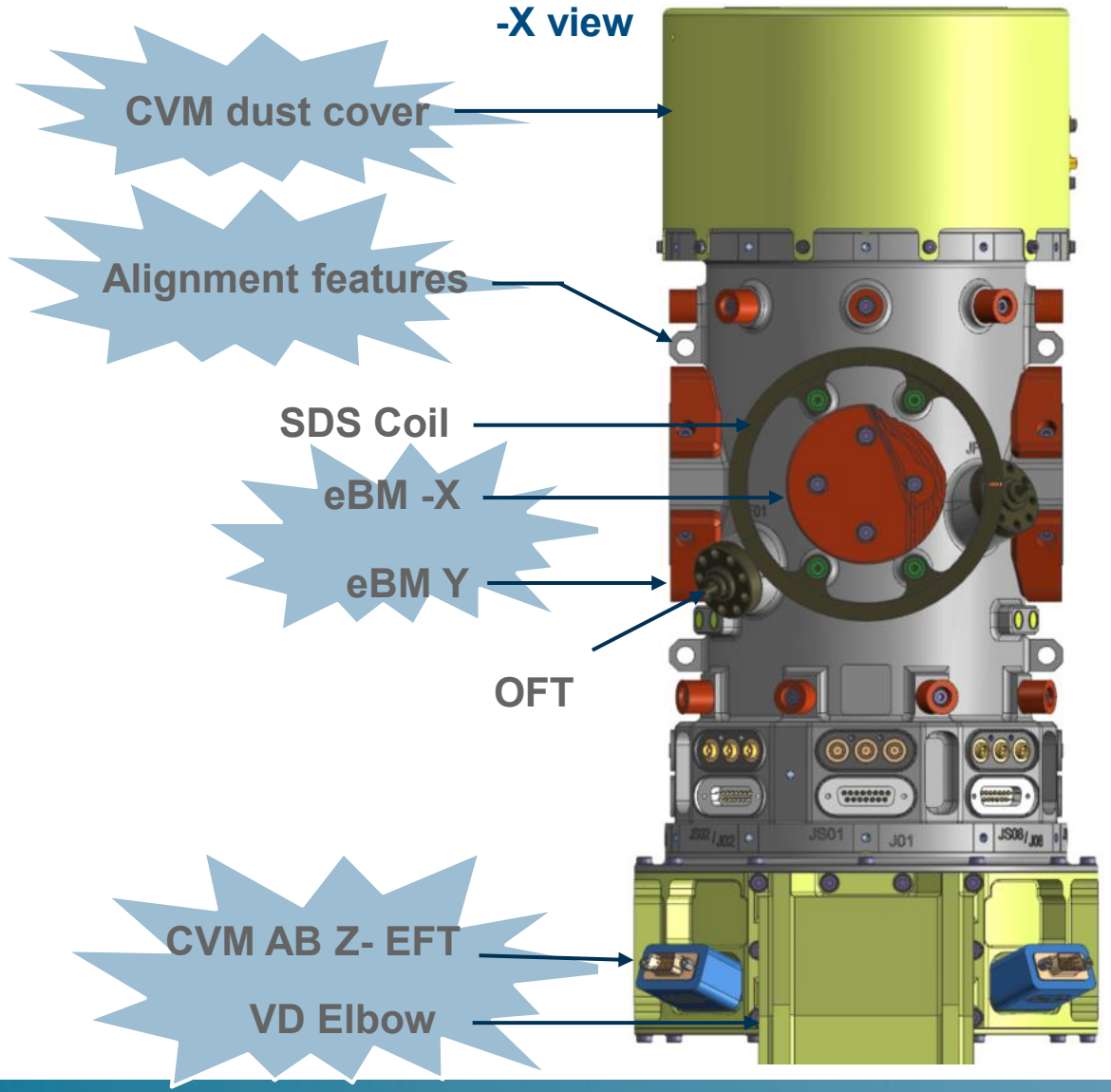
LISA GRS Head Design at PDR





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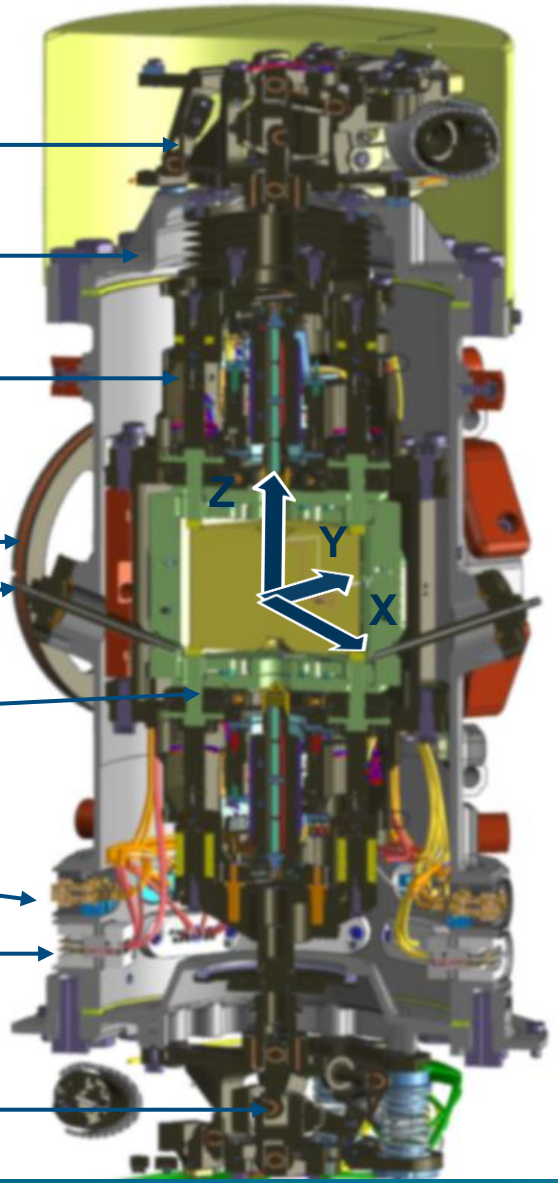
LISA GRS Head Design at PDR



CVM Actuator Block Z+

VC top cover

CVM Transmission Stage

SDS Coil

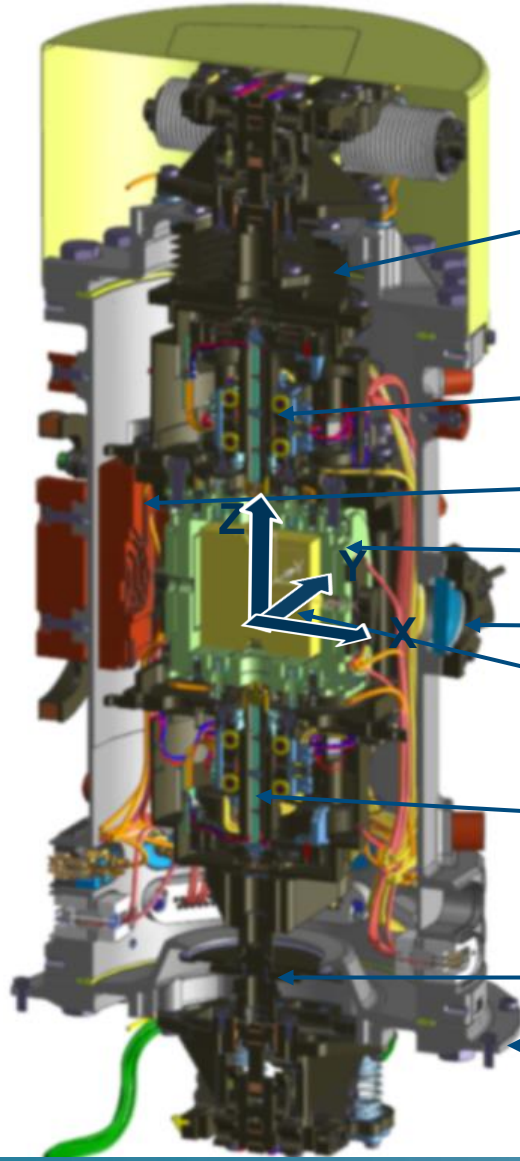
OFT

CVM Fingers

EFT Tricoax

EFT DSub

CVM Actuator Block Z-



CVM Bellow Assembly

GPRM Z+ (conical)

iBM

EH

OWA

TM

GPRM Z- (pyramidal)

CVM Valve

VC Bottom Cover

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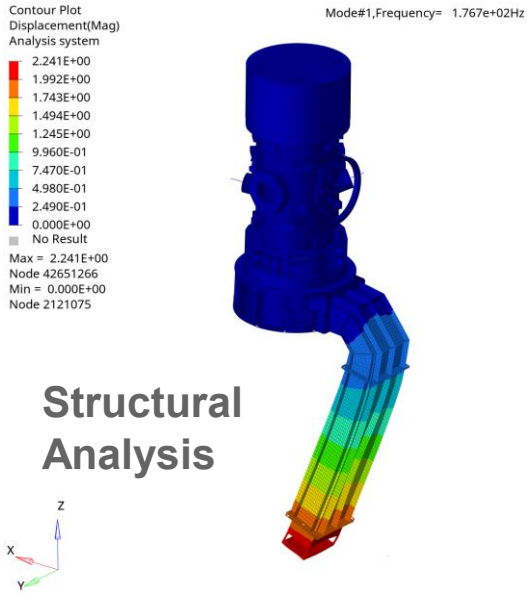
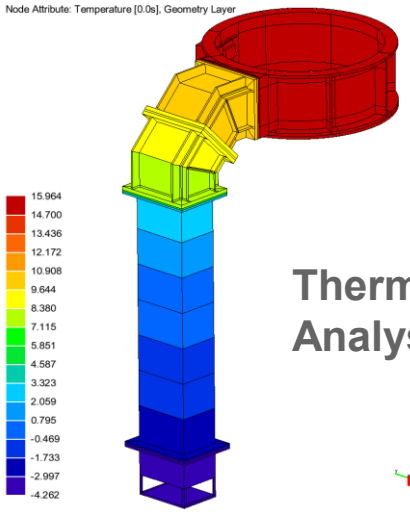
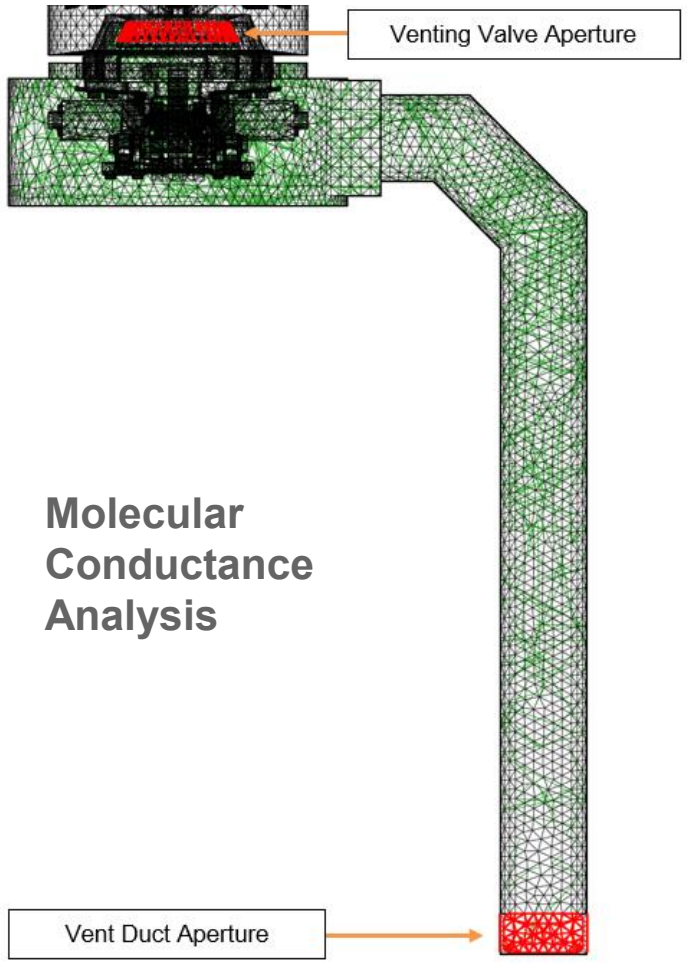
Vent Duct: a new design for LISA



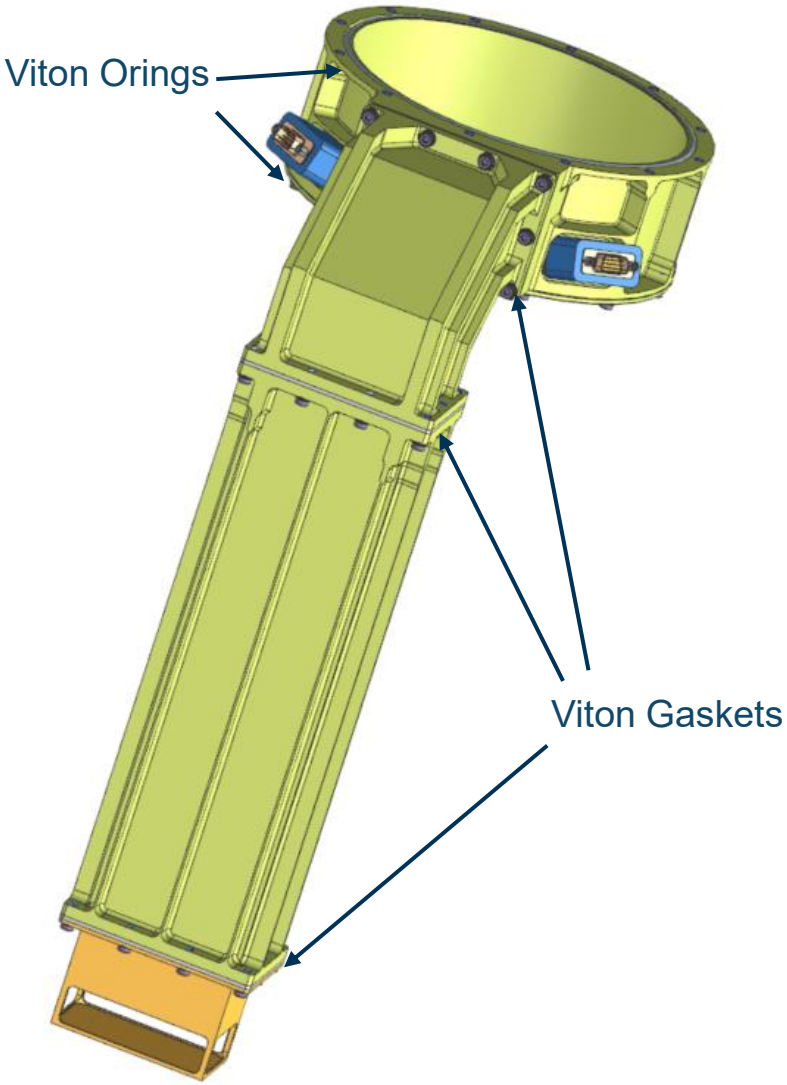
Structural Analysis



Thermal Analysis



Molecular Conductance Analysis



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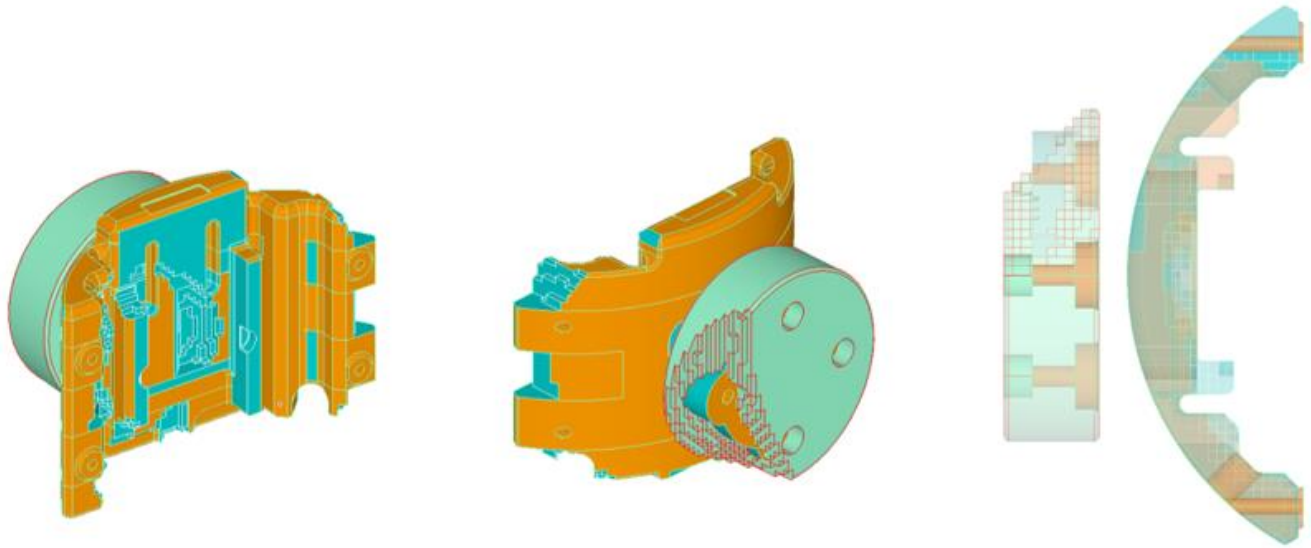
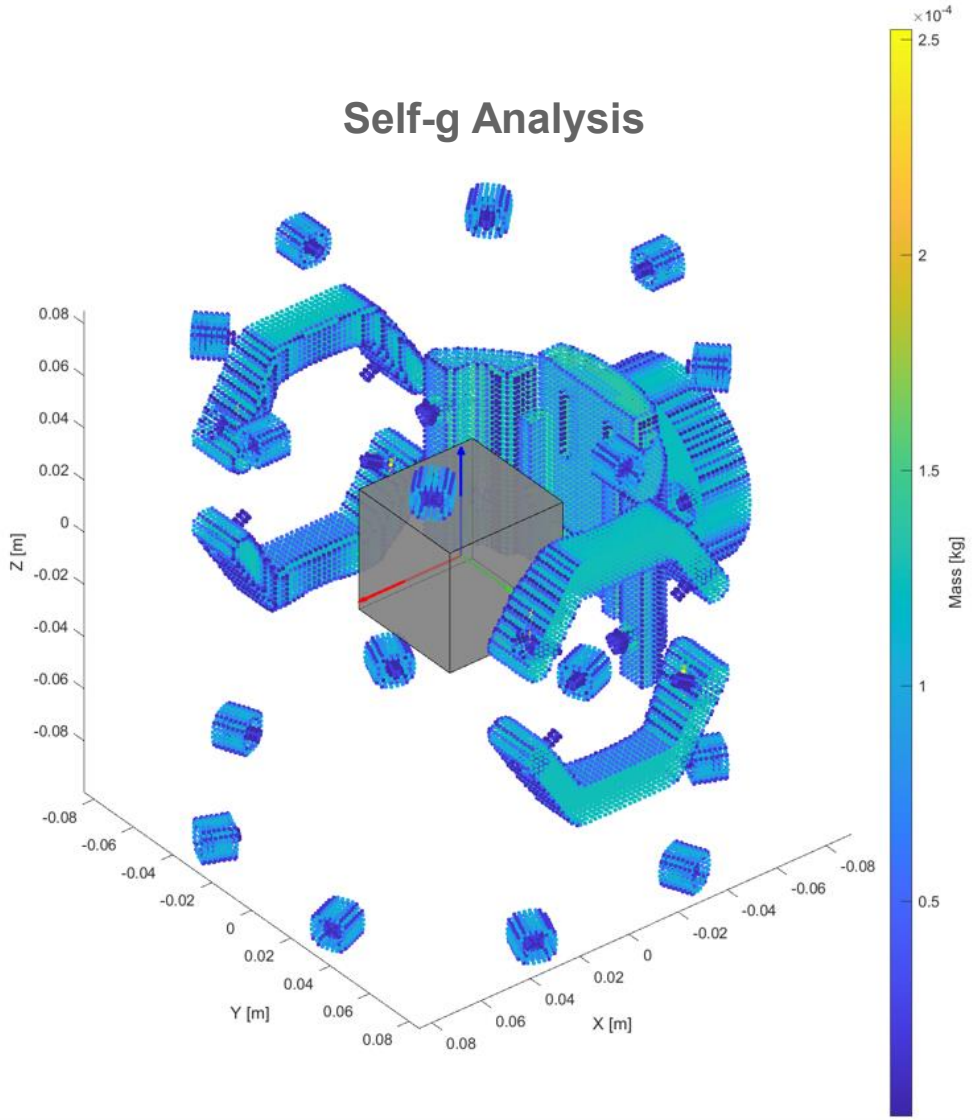
Balance Mass: a more accurate analysis for LISA

- Mass model for GRSH generated to comply to more stringent self-g requirements: DC forces, torques and stiffness
- Self-g Balancing: IBMX, EBMX duly shaped to achieve balancing while keeping torque and stiffness within budgets
- No need of EBMY for the applicable Balancing target



Internal and External BMs shaping

Self-g Analysis



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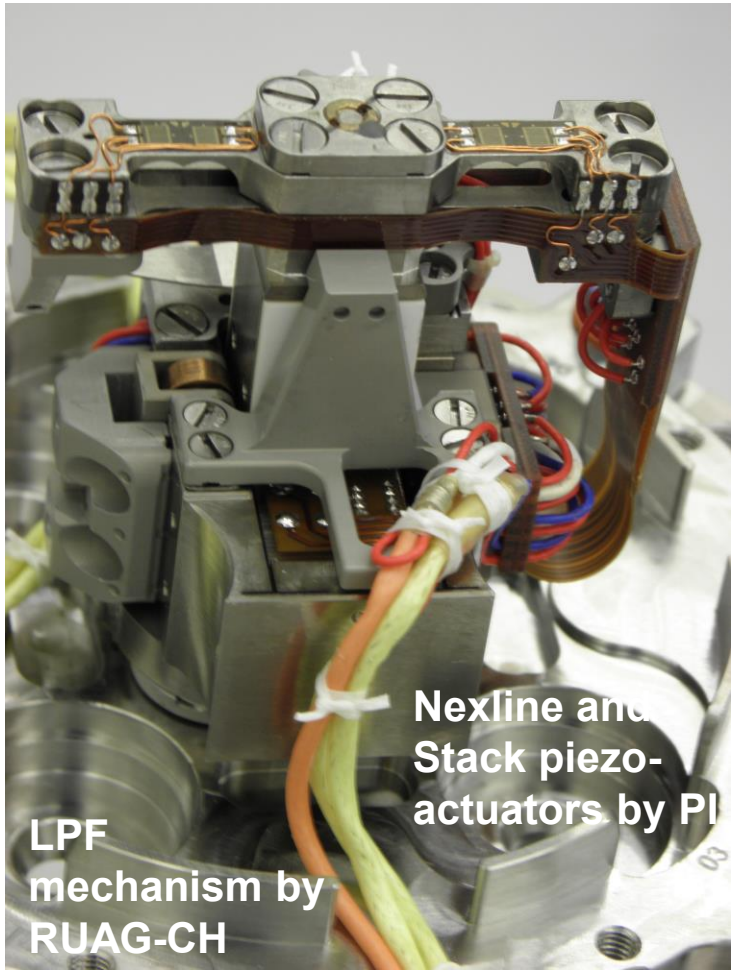
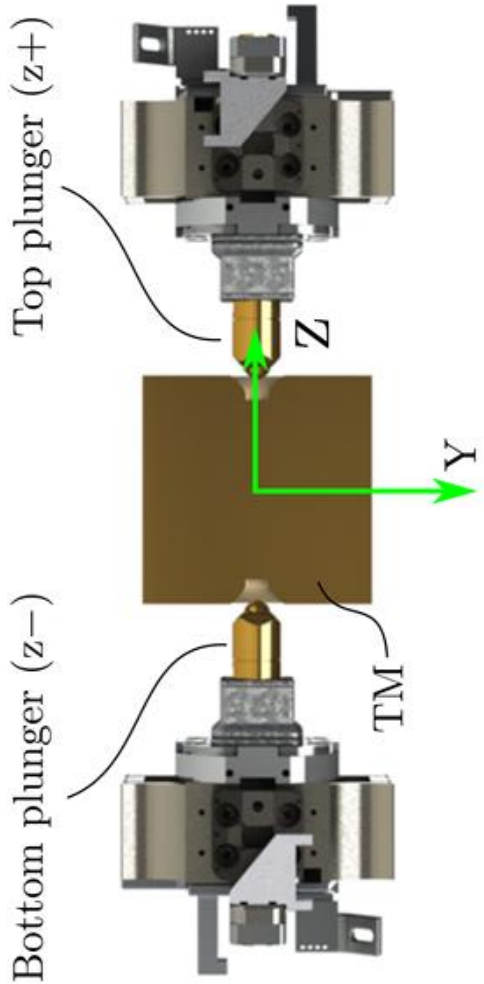
Grabbing Positioning and Release Mechanism

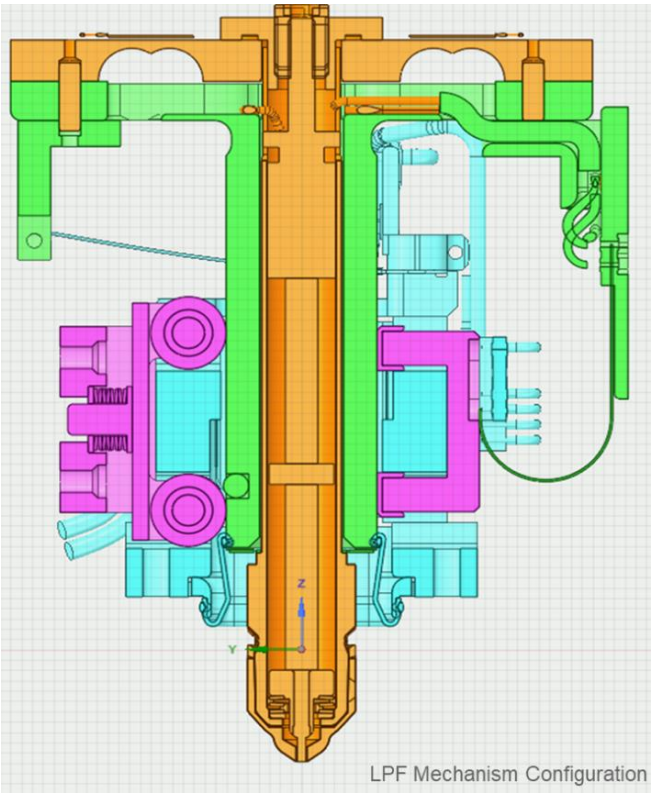
GPRM is composed of 2 mechanisms, that Grab, Position, and Release the TM



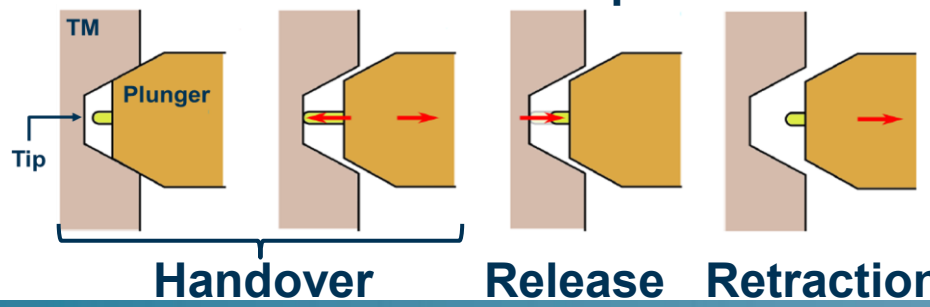


Moving Part:
- Linear Runner
- Plunger unit
  - Force Sensor
  - Piezo Stack
  - Release Tip

Fixed Part:
- Piezo-Walk Actuator Unit
- Position Sensor
- Side-Guiding
  - Fix Sliders
  - Flex Rollers


LPF Mechanism Configuration

TM Release Steps



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GPRM Design Improvements for LISA: Why

- **Experimental flight results:**
  - → 46 TM releases performed for each TM at the end of mission
  - → very different results for TM1 and TM2
- **Analysis of LPF in-flight data suggests that plunger impacts the TM at release**
- **Main identified issues:**
  - → Low TM-to-plunger gap
  - → Lateral motion of the plunger at the handover/release/retraction phases, plunger vibration
  - → Unreliable preload at release due to noisy force sensor

TM1 Pre-Release State [m] / [rad]						TM1 Release Velocity [um/s] / [urad/s]						
x1	y1	z1	the1	eta1	phi1	x1	y1	z1	the1	eta1	phi1	Comments
8.2E-06	-4.6E-05	8.8E-07	-1.9E-04	3.9E-04	1.8E-04	<1	<1	<1	<60	<60	<60	
1.2E-05	-8.0E-05	-2.2E-06	-4.5E-04	7.3E-04	7.0E-04	<1	<1	1.5	<40	<40	<40	
1.5E-05	-8.0E-05	-1.4E-06	-4.5E-04	6.2E-04	7.7E-05	<1	<1	<1	<60	<60	<60	
1.3E-05	-8.0E-05	-3.4E-06	-4.3E-04	6.5E-04	-4.2E-05	<1	<1	<1	<75	<75	<75	
1.3E-05	-7.9E-05	-4.1E-06	-4.5E-04	6.9E-04	4.5E-04	<1	<1	<1	<75	<75	<75	
1.2E-05	-7.9E-05	1.3E-05	-3.7E-04	7.5E-04	7.6E-04	-2	<1	-2	-10	109	31	
1.2E-05	-7.8E-05	5.1E-06	-3.8E-04	7.7E-04	7.9E-04	<1	-3	-3	<200	<200	223	
1.4E-05	-7.9E-05	2.5E-05	-3.9E-04	7.0E-04	1.8E-04	-1	<1	-1	20	121	-13	
1.4E-05	-8.0E-05	5.2E-06	-4.0E-04	7.2E-04	9.4E-04	<1	<1	-2	0	116	0	
1.4E-05	-7.9E-05	5.1E-06	-4.0E-04	7.6E-04	-9.9E-05	-2	<1	-2	10	130	-26	
1.4E-05	-8.0E-05	6.6E-06	-3.6E-04	7.6E-04	-6.9E-05	0	0	-2	0	141	-181	
1.3E-05	-8.0E-05	5.3E-06	-4.1E-04	8.1E-04	7.9E-04	-2	<1	-2	41	140	-70	
1.6E-05	-8.0E-05	9.1E-06	-3.5E-04	6.8E-04	1.5E-03	<1	<1	<1	0	88	-40	
1.5E-05	-8.1E-05	6.3E-06	-4.2E-04	8.3E-04	7.9E-04	-2	<1	-2	-10	170	-60	
1.6E-05	-8.1E-05	6.7E-06	-4.6E-04	7.9E-04	2.3E-03	-6	0	-6	-42	200	0	
1.4E-05	-8.1E-05	8.3E-06	-5.1E-04	6.9E-04	7.1E-04	<1	<1	<1	<40	<40	<40	
1.9E-05	-8.3E-05	8.1E-06	-3.6E-04	7.2E-04	4.5E-04	-7	0	-8	0	-300	0	
1.5E-05	-8.3E-05	6.4E-06	-3.0E-04	8.7E-04	1.0E-03	-7	<1	-7	-31	-270	-47	
1.7E-05	-8.4E-05	7.7E-06	-2.9E-04	7.8E-04	2.8E-03	<1	<1	<1	0	51	0	
2.3E-05	-8.1E-05	7.4E-06	-4.1E-04	4.8E-04	1.2E-03	-6	-2	-6	-65	-315	-52	
1.7E-05	-8.5E-05	9.2E-06	-3.0E-04	7.8E-04	7.5E-04	0	0	0	0	0	1910	Something very strange happened on t
2.1E-05	-8.6E-05	9.2E-06	-3.0E-04	6.8E-04	1.4E-03	-6	<1	-7	23	-330	-42	
1.3E-05	-8.5E-05	8.6E-06	-3.9E-04	6.0E-04	-1.2E-03	<1	<1	<1	<40	<40	<40	
1.7E-05	-8.4E-05	9.9E-06	-4.3E-04	8.3E-04	-1.7E-04	<1	<1	-3	30	52	-30	
1.5E-05	-8.7E-05	7.8E-06	-2.9E-04	8.6E-04	6.6E-04	0	0	0	0	0	-1000	Completely not understandable...
1.5E-05	-8.4E-05	7.6E-06	-3.5E-04	7.7E-04	1.3E-03	<1	<1	<1	13	72	-77	
1.6E-05	-8.4E-05	7.9E-06	-2.5E-04	5.1E-04	1.6E-04	<1	<1	-3	0	-68	-55	
1.5E-05	-8.4E-05	5.5E-06	-3.0E-04	4.6E-04	-3.0E-04	<1	<1	<1	40	60	-21	
1.2E-05	-8.4E-05	6.9E-06	-2.7E-04	7.1E-04	6.8E-04	-2	<1	-1	<100	<100	<100	
1.5E-05	-8.4E-05	6.6E-06	-2.7E-04	6.5E-04	-8.9E-04	<1	<1	<1	17	31	10	
1.7E-05	-8.6E-05	1.1E-05	-1.9E-04	8.6E-04	1.1E-03	6	15	0	-1060	0	0	Impacts
1.6E-05	-8.5E-05	7.1E-06	-1.8E-04	8.2E-04	5.7E-04	<1	<1	<1	16	41	-10	
1.6E-05	-8.6E-05	6.9E-06	-1.8E-04	8.9E-04	5.1E-04	-5	0	1.2	<100	<100	<100	
1.4E-05	-8.4E-05	9.6E-06	-2.5E-04	8.0E-04	5.0E-04	<1	2	-3	130	39	59	
1.6E-05	-8.6E-05	7.2E-06	-2.0E-04	8.5E-04	1.2E-04	-2	-2	<1	<100	<100	-212	
1.9E-05	-8.4E-05	7.9E-06	-2.7E-04	5.3E-04	-5.8E-05	<1	<1	-1	15	-32	39	
1.7E-05	-8.4E-05	7.2E-06	-2.2E-04	7.6E-04	4.9E-04	<1	<1	<1	<40	<40	<40	
1.5E-05	-8.6E-05	7.3E-06	-1.8E-04	8.6E-04	8.8E-04	<1	<1	<1	35	60	13	
1.1E-05	-8.4E-05	8.3E-06	-2.4E-04	4.0E-04	1.0E-03	<1	<1	<1	<100	<100	<100	
1.7E-05	-8.5E-05	9.5E-06	-2.2E-04	7.6E-04	1.4E-03	13	-2	6.8	-74	330	-95	
1.7E-05	-8.5E-05	7.9E-06	-2.3E-04	7.7E-04	-6.3E-04	-7	-1	-7	92	-300	171	
1.6E-05	-8.5E-05	8.7E-06	-2.1E-04	8.2E-04	1.4E-03	<1	<1	<1	4	38	-25	
1.6E-05	-8.5E-05	7.3E-06	-2.3E-04	8.4E-04	1.8E-04	-3	<1	-2	-15	100	-24	
1.6E-05	-8.4E-05	8.4E-06	-1.9E-04	6.9E-04	-1.2E-03	<1	<1	<1	16	16	52	
1.8E-05	-8.4E-05	8.2E-06	-2.7E-04	6.4E-04	5.4E-03	<1	<1	<1	5	58	-286	
1.6E-05	-8.6E-05	7.4E-06	-2.3E-04	5.2E-04	5.6E-03	3	<1	9	75	-215	-124	Impact during slow retract

TM2 Pre-Release State					TM2 Release Velocity [um/s] / [urad/s]						
z2	the2	eta2	phi2	x2	y2	z2	the2	eta2	phi2	Comments
1.0E-05	1.4E-04	-1.2E-03	2.5E-03			-100				Followed -Z Plunger
6.8E-06	1.8E-04	-1.2E-03	3.4E-03			-40		860		
-1.2E-06	-8.9E-06	-1.2E-03	2.6E-03	0	37	66	0	0	0	
8.6E-07	6.3E-05	-1.2E-03	3.6E-03	6	-3.3	-4	200	200	-1400	
2.0E-07	1.5E-05	-1.3E-03	2.9E-03	3	<1	<1	-83	308	-473	
9.5E-07	-2.4E-05	-1.3E-03	4.2E-03	-10	6.5	-6.3	-100	-1000	1700	
2.1E-06	1.1E-04	-1.3E-03	3.1E-03	0	0	-20	0	560	0	ETA Lost control after c
-1.5E-06	7.9E-05	-1.3E-03	1.8E-03	4	-4.5	7.8	-400	320	-2500	
1.6E-06	-4.4E-05	-1.2E-03	2.1E-03	5	3.2	-4	45	141	58	
-1.2E-06	7.1E-06	-1.2E-03	1.4E-03	6	6	-35	-100	-430	-1000	Impacted in Z
4.0E-07	-1.2E-04	-1.3E-03	3.5E-03	5	0	-7.5	0	268	-232	
-2.1E-08	7.6E-05	-1.3E-03	1.6E-03	18	5	-10	80	420	-2500	
5.0E-07	-4.5E-05	-1.2E-03	4.9E-03	5	1.3	-4	59	187	-289	
4.0E-07	-4.9E-05	-1.3E-03	2.6E-03	-2	-10	-25	-1740	135	1250	
8.1E-05	-8.3E-04	-1.1E-03	-2.6E-02	-6	4.5	0	0	0	748	
9.2E-07	-7.3E-05	-1.2E-03	-9.9E-04	-6	-7	4.3	-540	-300	580	
1.6E-06	-1.1E-04	-1.3E-03	4.6E-03	3	4	0	0	0	-1430	Stopped, but lost control
5.1E-05	-3.2E-04	-1.1E-03	-1.6E-02	0	0	0	0	0	10000	
8.7E-05	-1.7E-04	-1.4E-03	2.7E-02	4	1.2	-6	-58	300	-228	
5.3E-07	-1.8E-04	-1.3E-03	2.2E-03	-12	11	8	-340	13	-3300	
3.3E-07	-1.7E-04	-1.3E-03	2.8E-03	6	0	0	0	-250	0	
-1.1E-07	-1.5E-04	-1.3E-03	3.0E-04	4	1.4	-4.5	-77	95	290	
7.0E-07	-1.3E-04	-1.3E-03	3.0E-03	8	0	3.8	0	448	0	
6.2E-07	-1.7E-04	-1.3E-03	2.9E-03	5	7	-7	-256	211	60	
2.7E-07	-1.1E-04	-1.2E-03	4.9E-03	6	0	-6	0	220	-187	
1.7E-06	-1.4E-04	-1.1E-03	4.2E-03	3	10	7.3	1210	160	-1520	
1.9E-06	-1.3E-04	-1.3E-03	1.2E-03	7	0	0	<200	<200	<200	
6.3E-07	-1.5E-04	-1.0E-03	-2.6E-03	0	6.3	-7.3	-142	720	-3500	
1.2E-06	-1.5E-04	-1.3E-03	2.5E-03	0	15	-5	-1200	0	0	Impacts
1.0E-06	-9.3E-05	-1.2E-03	2.2E-04	<1	27	13	300	200	-200	Impacts
1.3E-06	-1.2E-04	-1.2E-03	-7.5E-04	4	0	4.4	0	0	547	
2.2E-06	-8.5E-06	-1.1E-03	2.1E-04	20	-5.2	5.1	185	-855	1600	
9.0E-05	-1.0E-04	-1.1E-03	3.3E-02	4	0	-2.4	0	0	-568	
1.7E-06	-1.6E-04	-1.1E-03	1.9E-03	<1	-19	-5	1110	253	213	Impacts
2.1E-06	-1.1E-04	-1.3E-03	-4.2E-04	-4	2.3	-5.5	-70	300	800	
2.3E-06	1.8E-05	-1.3E-03	9.3E-04	49	7.5	-20	360	-778	450	
1.7E-06	-6.7E-05	-1.1E-03	-3.0E-04	1	4.5	-2	-260	<100	205	
3.4E-06	-1.3E-04	-1.2E-03	4.8E-03	-33	-129	-121	6700	1700	-6345	
4.5E-05	-9.8E-04	-5.8E-04	-6.2E-03	8	<1	7	<100	-313	0	
1.6E-06	-1.2E-04	-1.2E-03	4.8E-03	3	41	-15	-1210	140	830	Impacts
1.8E-06	-1.6E-04	-1.2E-03	3.7E-03	-1	1	4	100	-80	-800	
2.6E-06	-1.8E-04	-1.1E-03	4.3E-03	<1	-1.7	-5.8	124	-46	-127	
3.0E-06	-9.1E-05	-1.2E-03	2.7E-03	0	0	0	0	0	3170	
8.8E-05	-1.7E-04	-1.1E-03	3.2E-02	5	2.9	7	113	320	-449	Extreme xtalk X-PHI
1.4E-06	-5.3E-05	-1.2E-03	4.6E-03	4	-8.4	2.8	-249	-100	-1165	Impact during slow plung
2.1E-06	-8.0E-05	-1.2E-03	-1.2E-03	22	8	11	-125	-284	-1722	

LPF data: courtesy of ESA

Need to improve the GPRM design for a safe, reliable and autonomous TM release.

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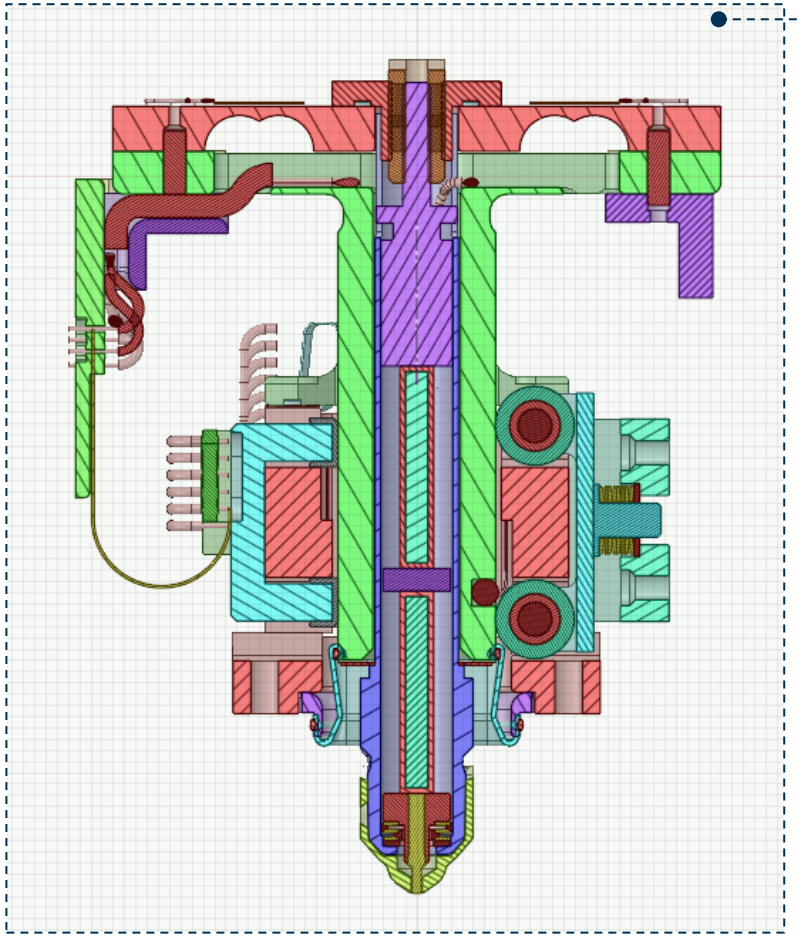
GPRM Design: road from LPF to LISA



LPF

GPRM from RUAG

LPF GPRM in-flight performance analysis

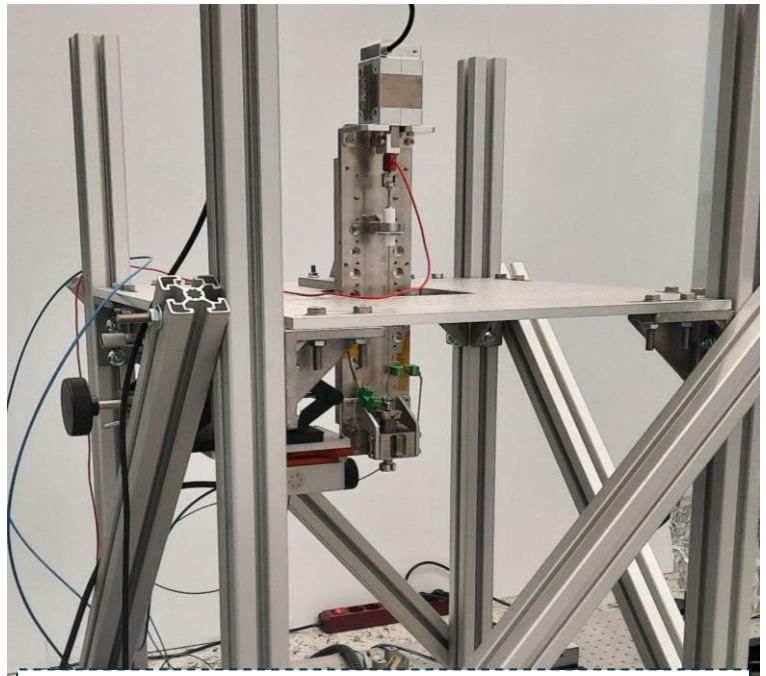
LISA

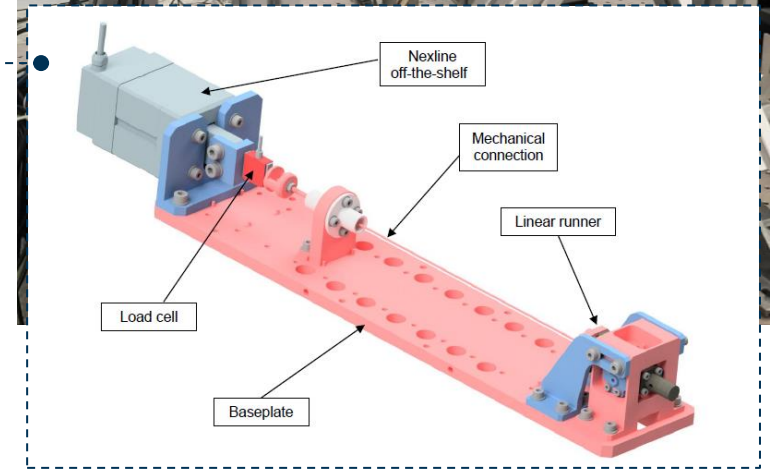
Technology Transfer RUAG → OHB-I

Evaluations of Design Improvements

Breadboard Tests

EM Baseline Definition





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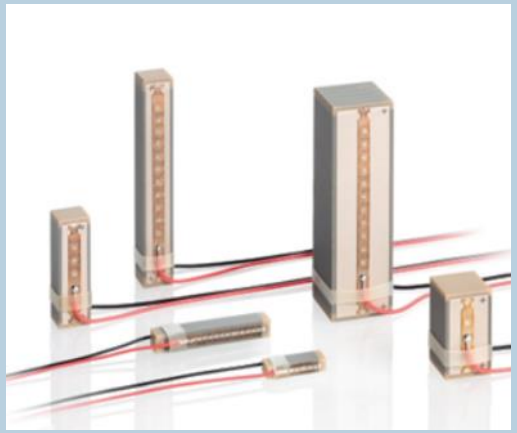
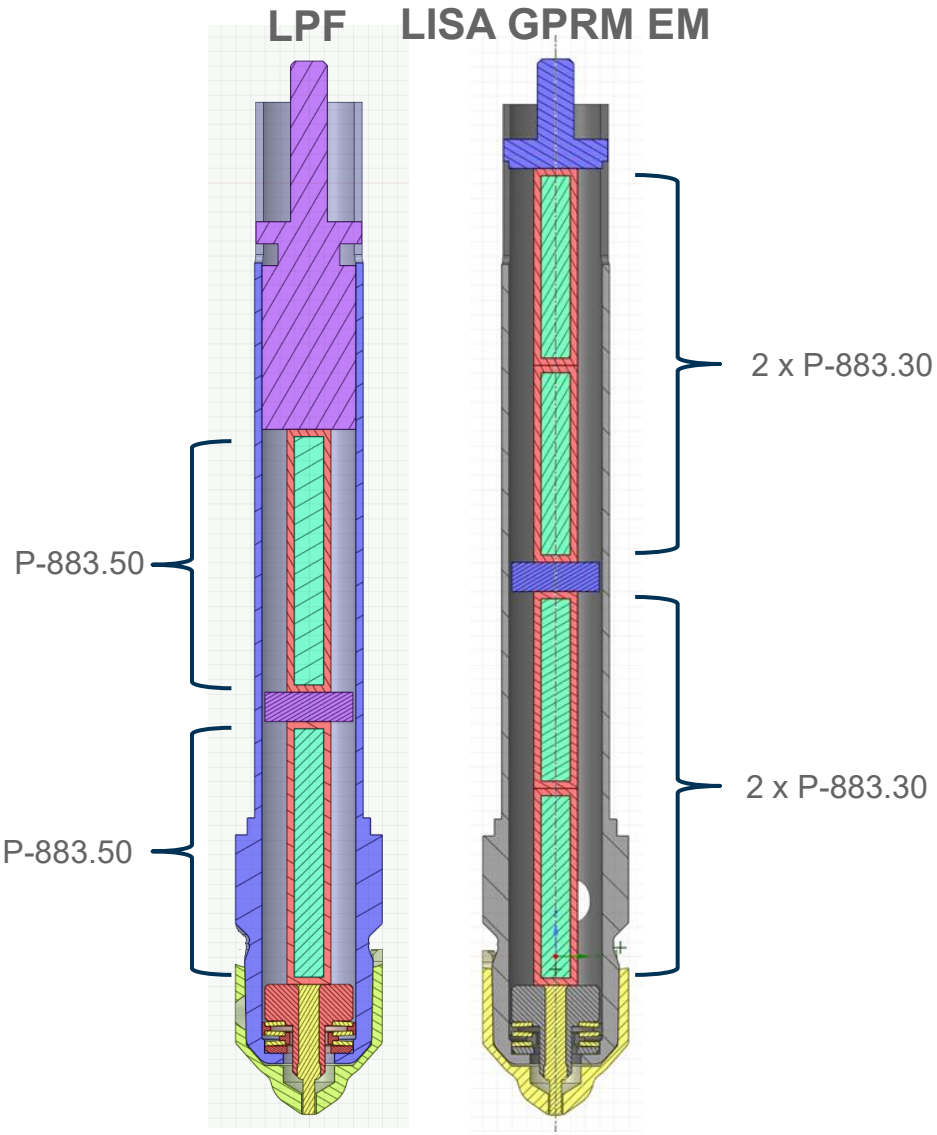
GPRM Main Design Improvements (1)

- A **longer tip stroke** is a fundamental to increase the gap and reduce the risk of TM re-contact after release
- Change of release tip piezoelectric actuator
  - → 2 glued COTS Actuators per redundancy
  - → Increased stroke by ~50%
  - → Maximization of LPF heritage: minor mechanical changes
- Single COTS Actuators with same length under development at PI

PICMA® Stack Multilayer Piezo Actuators



PI



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GPRM Main Design Improvements (2)

- Mechanism operation relies on force reading

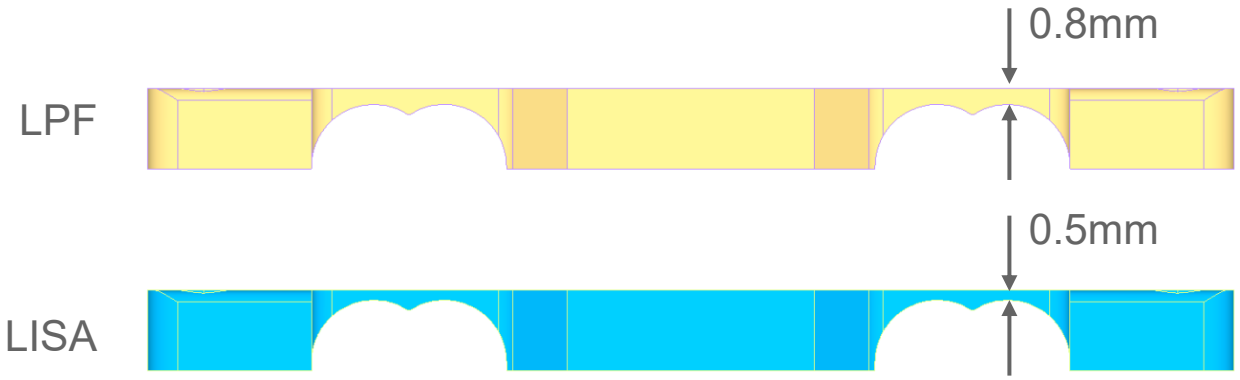
  → The lower the preload at TM release the lower the impulse

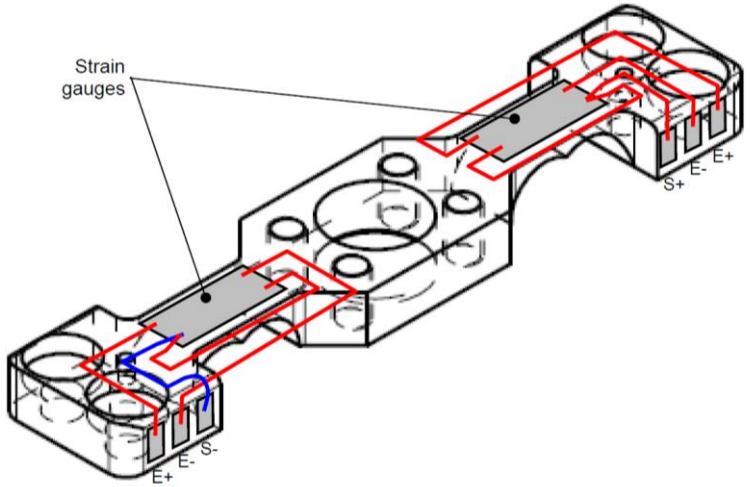
- Force sensor optimized by decreasing thickness of deformable parts where strain gauges are located

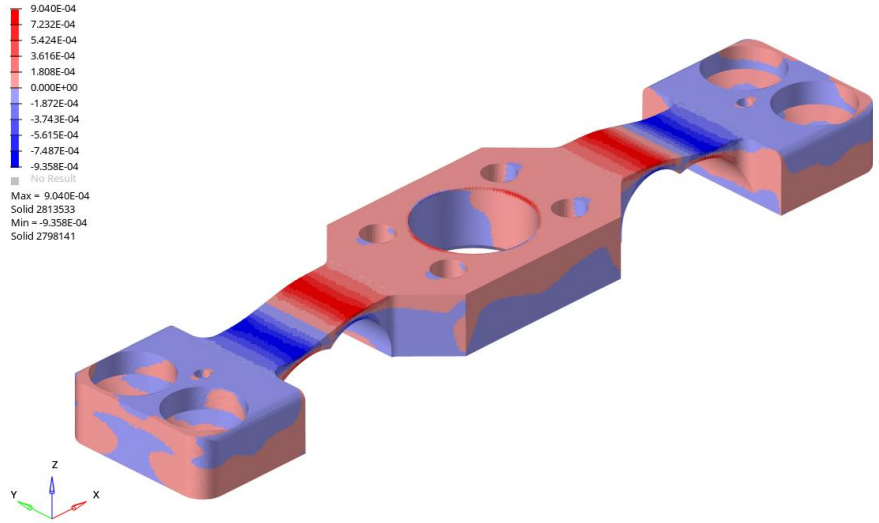
  → Increased (doubled) sensitivity

  → Reduced stiffness has no detrimental effect on mechanism performance

  → Low Noise Sensor readout (implemented on MCU)







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GPRM Main Design Improvements (3)

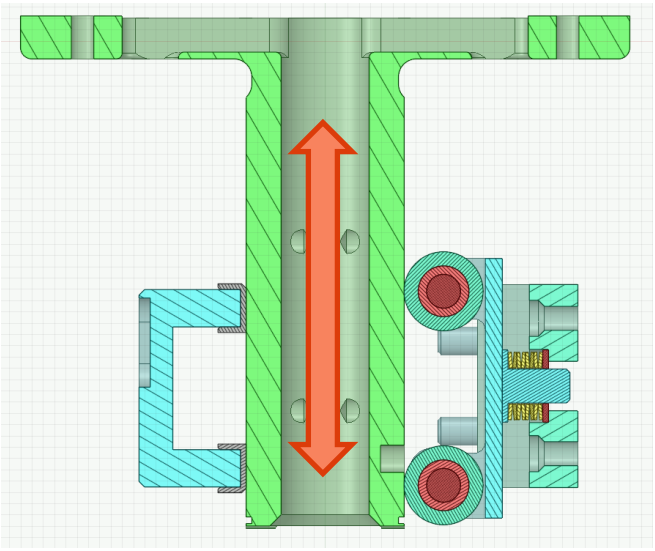
- Side-movement at motion inversion causes plunger-TM impact

  → Configurations tested on BB model

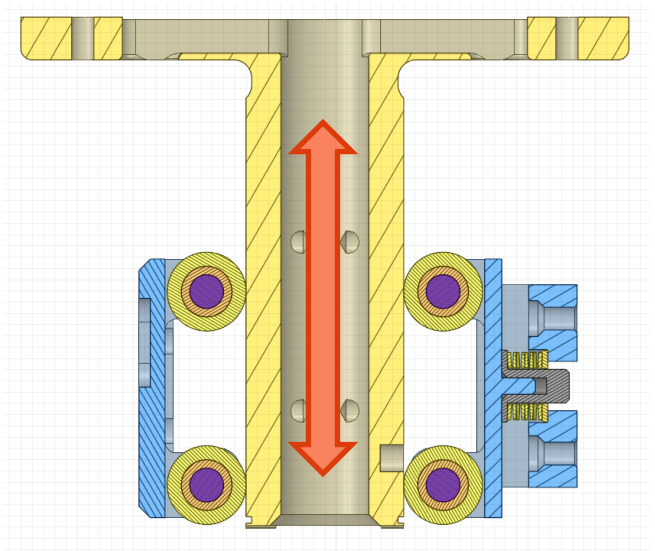
  → Roller-roller is new baseline for LISA

  - *Lower lateral movement close to TM with lower risk of re-impact*
  - *Higher movement on long stroke due to roller run-out does not affect release performances*

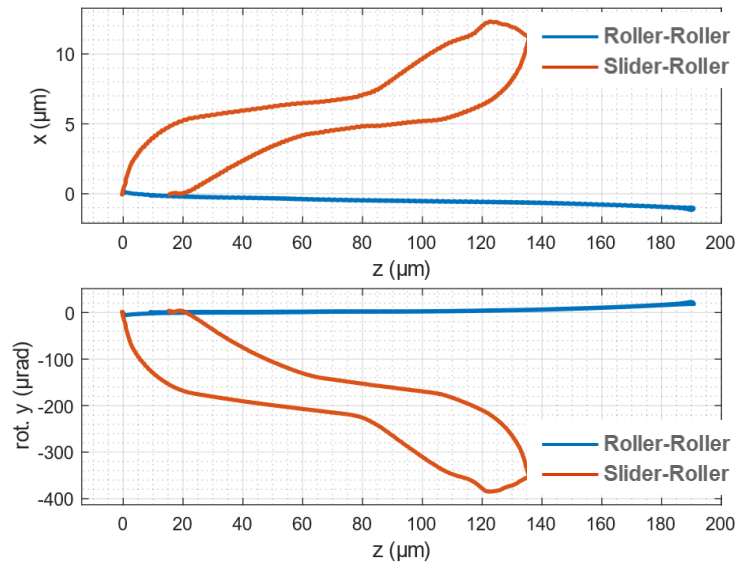
LPF: Slider-Roller



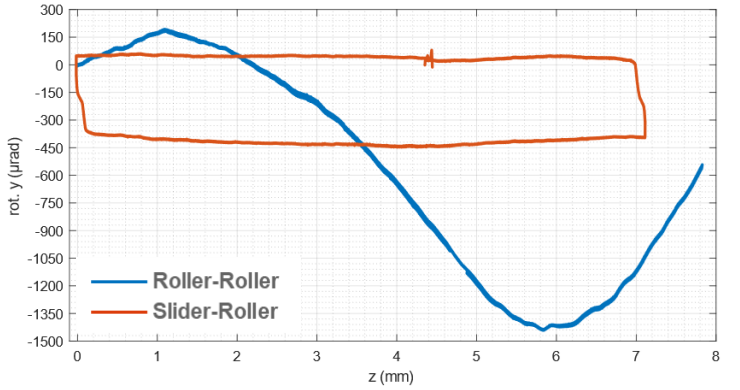
LISA: Roller-Roller



Short Stroke Test close to release position



Long Stroke Test



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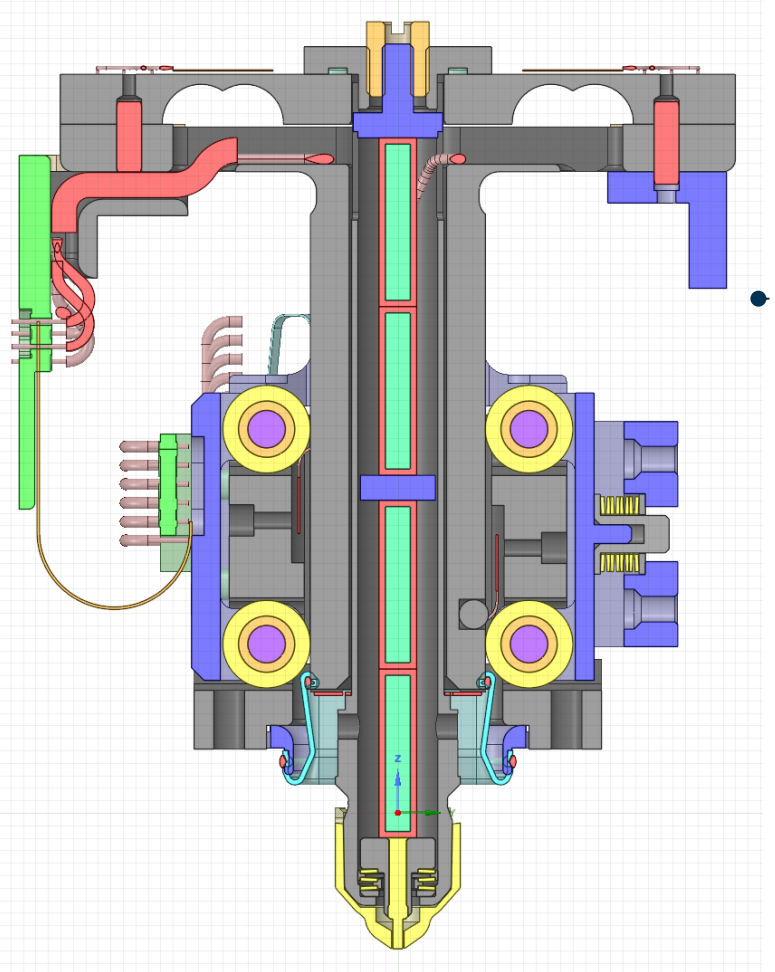
GPRM Status: Current and Next Activities



EM Baseline Definition & Design Finalization

EM Integration

EM Tests Detailed Definition & Execution

QM and FM MAIT

- *Demonstrate the capability of re-building GPRM*
- *Debugging and optimization of integration procedures and support equipments for next models*

- *Verification of mechanism performance*
- *Consolidate grabbing, positioning and release procedures*
- *Characterization of adhesion forces*
- *Verification of mechanism models*

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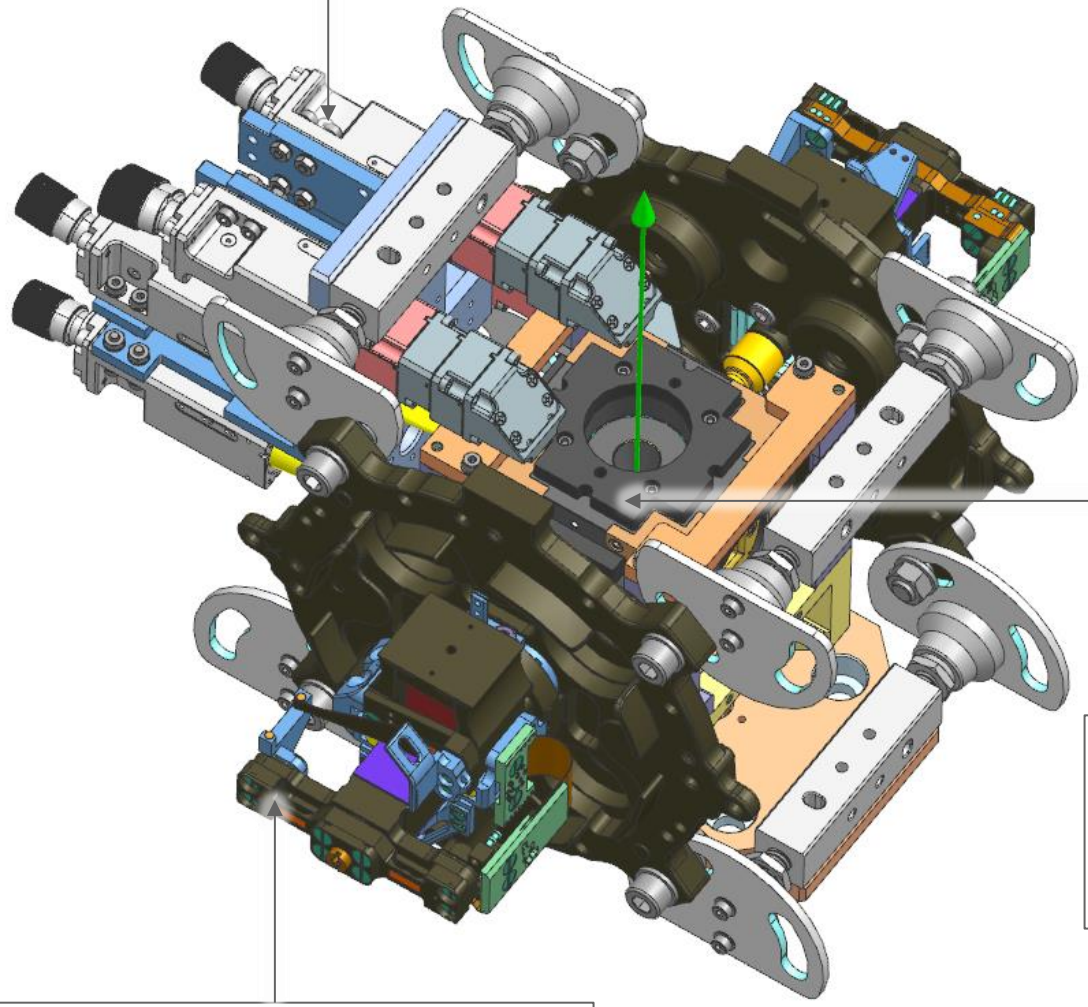
GPRM Co-alignment & Testing Improvements

6 non-contact displ. Sensors for TM 6DoF tracking

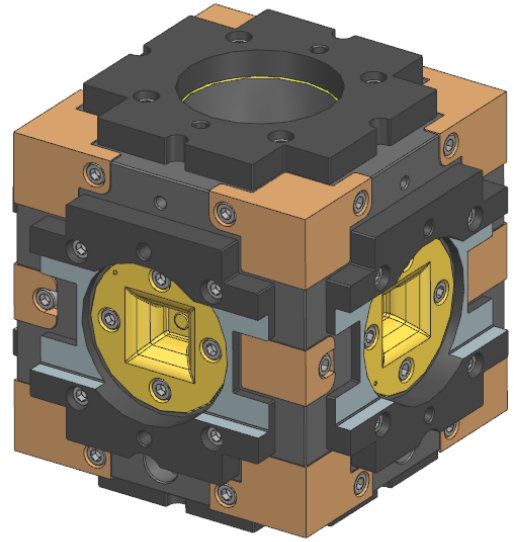


GPRM units mounted on FM Flanges

- Test setup built around TM (fixed)
  - → GPRM mounted on the flanges in nominal position
  - → GPRM optimally aligned with best-fit in TM indent (maximum penetration method)
- Test with suspended TM (free) to demonstrate grabbing and pre-release position/orientation

Dummy TM suspended in CoG for gravity free simulation.

2 couples of indents for TM manufacturing repeatibility estimation



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