LISA Technology Package (LTP)

System Design and Operation

LTP + LPF/DFACS Team

EADS Astrium GmbH

6th International LISA Symposium

23 June 2006

Guide to the Presentation

- LTP System Overview and Responsibilities
- LTP Accommodation on LISA Pathfinder
- Inertial sensor / Optical Metrology Alignment
- Test Mass Release by Caging Mechanism
- LTP Operations:
  Caging Mechanism Control Process
- Metrology Acquisition
- LTP Operations:
  Charge Management Control Process

LTP System Overview and Responsibilities

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LISA Pathfinder - LISA Technology Package (LTP) Mission Goals

- **Releasing Test Masses in an inertial system and, by using the „Drag-Free Attitude Control System (DFACS)“, to compensate for disturbing forces and torques acting on the test masses.**

- **Compensation quality shall demonstrate performance in terms of Acceleration Spectral Density and bandwidth, so that LISA requirements can be safely extrapolated.**

- Demonstration of **feasibility of a suitably accurate distance measurement techniques:**

  - **Laser-Heterodyn-Interferometry** with a determination accuracy of the time resolved Test Mass position and lateral attitude of
    $\mathbf{9 * 10^{-12}\ m\ Hz^{-1/2} * [1+(f/3mHz)^2]\ ;\ 10\ nrad/\ Hz^{-1/2}}$ **for** 3 – 30 mHz

  - **Capacitive sensors** for absolute distance measurements with accuracies of **< 3 nm/√Hz** in translation and **< 200 nrad /√Hz** in rotation

- **Demonstration of the feasibility to release test masses in orbit with residual disturbances to secure the drag-free mode operation**

LTP-Elements

Optical Metrology Subsystem (OMS)

➔ Measurement of Test Mass Position and –Attitude consisting of

- ➔ Optical Bench Interferometer
- ➔ Phasemeter
- ➔ Structure
- ➔ Laser Assembly incl.
  - ➔ Laser Head (RLU)
  - ➔ Laser Modulator (LM)

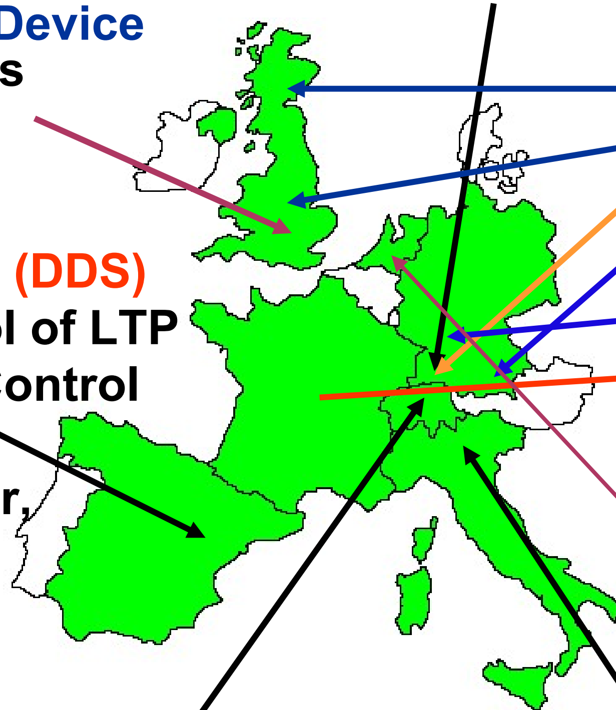
Charge Management Device

control of Test Masses

➔ Electric Charges

Data Management & Diagnostic Subsystem (DDS)

- ➔ Command & Control of LTP
- ➔ Optical Metrology Control
- ➔ Diagnostic Experiments (Heater, Magnetic Coils, Rad-Monitor, etc.)



Special Check-Out Equipment (SCOE) and Simulation SW

ISS Front-End Electronic

control of Test Masses

- ➔ Electrostatic actuation
- ➔ Electrostatic Position- and Attitude determination

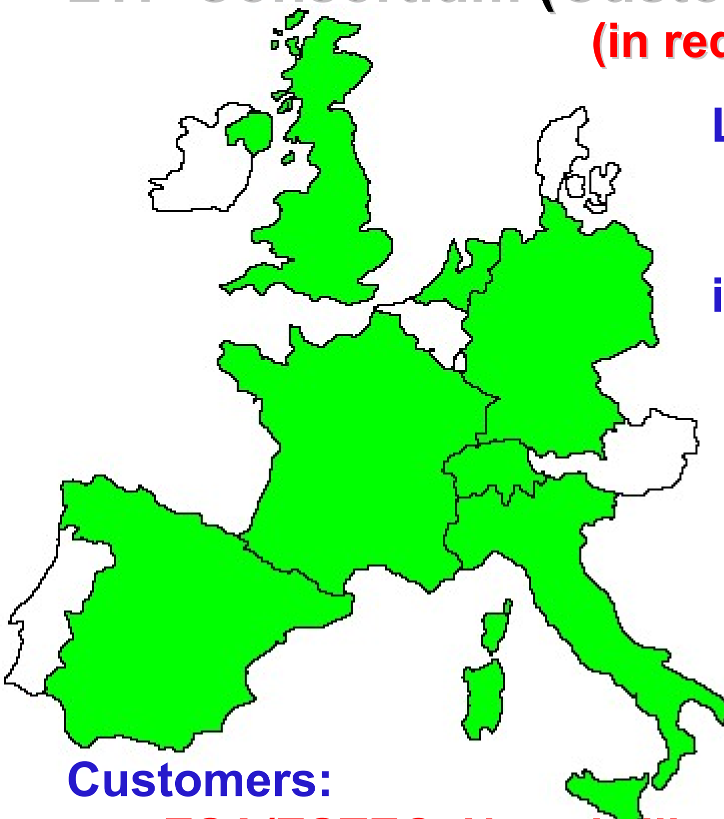
Inertial Sensor Subsystem (ISS)

control of Test Masses

- ➔ Electrostatic control (Electrode Housing)
- ➔ Environmental control (cleanlin., thermal 10^{-4} K/SQRT(Hz) , …)
- ➔ TM handling during launch and in Orbit (Caging Mechanism)

LTP Consortium (Customers, Sub-Co's, Suppliers)

(in red contractual relations to ASD)



LTP Architect:

EADS Astrium, Immenstaad, D

in cooperation with:

University of Trento, Italy (PI)

Albert-Einstein-Institut, Hannover (Co-PI)

ETH Zürich, Schweiz

Carlo Gavazzi, Mailand, Italy	→	ISS
Alenia-Laben, Mailand, Italy	→	CMA
Kayser-Threde, München, D	→	LA
Tesat, Backnang, D	→	RLU
University of Glasgow, UK	→	OBI
University of Birmingham, UK	→	PMA
Imperial College London, UK	→	CMD
Contraves, Zürich, CH	→	FEE, **LM**
SRON, Delft, Netherlands	→	IS SCOE
NTE, Barcelona, Spain	→	DDS

Customers:

ESA/ESTEC, Noordwijk

AEI/DLR, Germany

CNES, Paris, France

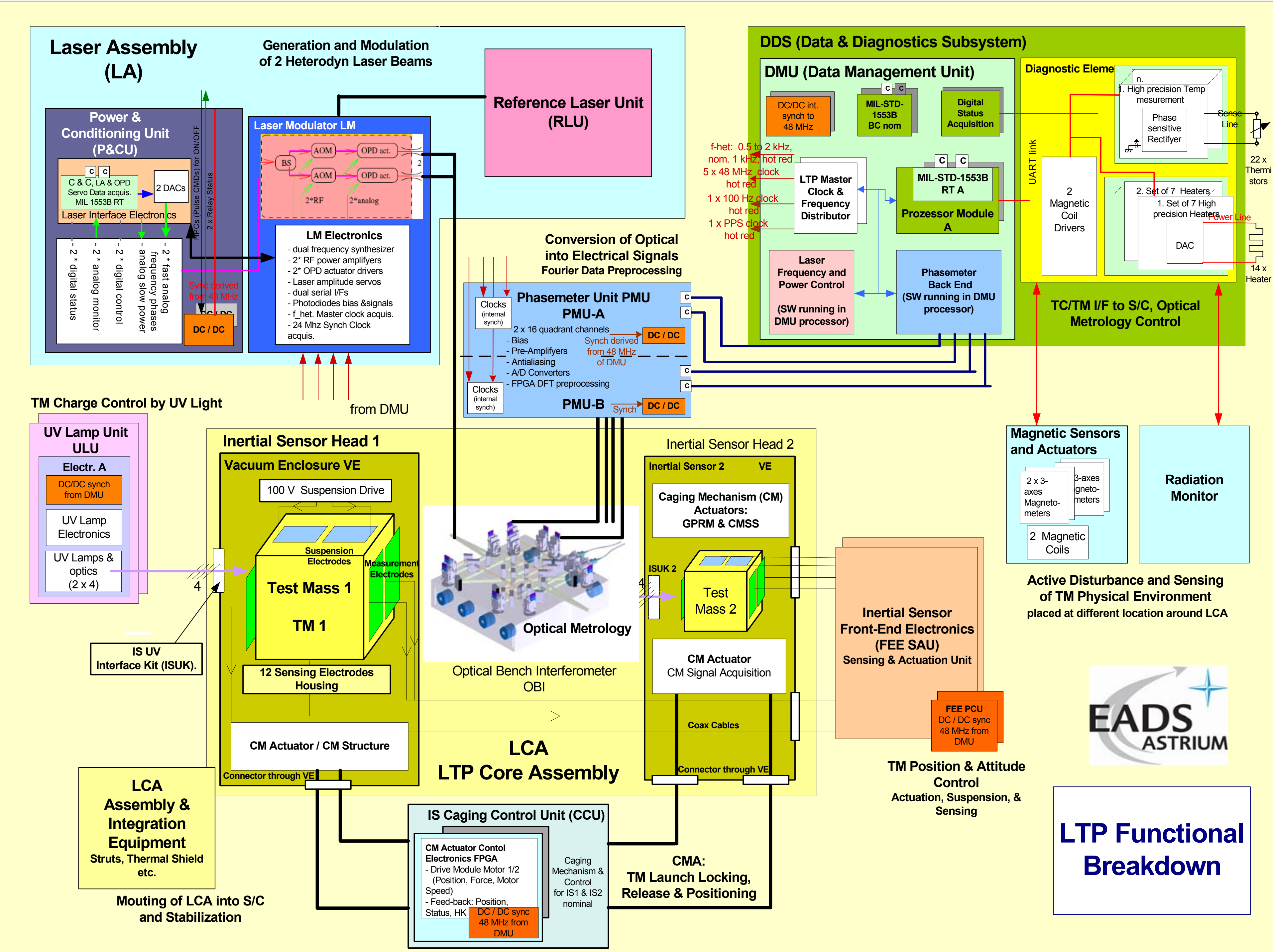
ASI, Rom, Italy

IEEC, Barcelona, Spain

PPARC, UK

Astrium Germany´s LTP Industrial Architect Role

- Overall System Engineering and LTP performance
- LTP Core Assembly system design
- Product Assurance
- Coordination of the contributions by other LTP Contributors
- Consolidate the LTP design on basis of previous activities Definition of LTP items for which no technical preparatory TRP programs were conducted
- Definition of LTP System and Unit requirements & definition of LTP SW modules
- Procurement of certain items (LA, RLU, CMA & LM)
- Integration of the LTP with respective GSE
- Test & Verification of LTP on instrument level
- Support of integration into the spacecraft and S/C level testing
- Support of in-orbit commissioning of LTP



Laser Assembly (LA)
Generation and Modulation of 2 Heterodyn Laser Beams
Reference Laser Unit (RLU)
Power & Conditioning Unit (P&CU)
C & C, LA & OPD Servo Data acquis. MIL 1553B RT
2 DACs
Laser Interface Electronics
- 2 * digital status
- 2 * analog monitor
- 2 * digital control
- analog slow power
- 2 * fast analog frequency phases
HPCs (Pulse CMDs) for ON/OFF
2 x Relay Status
Sync derived from 48 MHz
DC / DC
Laser Modulator LM
BS
AOM
OPD act.
2*RF
2*analog
LM Electronics
- dual frequency synthesizer
- 2* RF power amplifyers
- 2* OPD actuator drivers
- Laser amplitude servos
- dual serial I/Fs
- Photodiodes bias &signals
- f_het. Master clock acquis.
- 24 Mhz Synch Clock acquis.
from DMU
Conversion of Optical into Electrical Signals
Fourier Data Preprocessing
Phasemeter Unit PMU
PMU-A
Clocks (internal synch)
2 x 16 quadrant channels
- Bias
- Pre-Amplifyers
- Antialiasing
- A/D Converters
- FPGA DFT preprocessing
Synch derived from 48 MHz of DMU
DC / DC
PMU-B
Synch
DDS (Data & Diagnostics Subsystem)
DMU (Data Management Unit)
DC/DC int. synch to 48 MHz
MIL-STD-1553B BC nom
Digital Status Acquisition
f-het: 0.5 to 2 kHz, nom. 1 kHz, hot red
5 x 48 MHz clock hot red
1 x 100 Hz clock hot red
1 x PPS clock hot red
LTP Master Clock & Frequency Distributor
MIL-STD-1553B RT A
Prozessor Module A
Laser Frequency and Power Control (SW running in DMU processor)
Phasemeter Back End (SW running in DMU processor)
UART link
Diagnostic Eleme
n. 1. High precision Temp mesurement
Phase sensitive Rectifyer
Sense Line
22 x Thermistors
2 Magnetic Coil Drivers
2. Set of 7 Heaters
1. Set of 7 High precision Heaters
Power Line
DAC
14 x Heater
TC/TM I/F to S/C, Optical Metrology Control
TM Charge Control by UV Light
UV Lamp Unit ULU
Electr. A
DC/DC synch from DMU
UV Lamp Electronics
UV Lamps & optics (2 x 4)
IS UV Interface Kit (ISUK).
Inertial Sensor Head 1
Vacuum Enclosure VE
100 V Suspension Drive
Suspension Electrodes
Measurement Electrodes
Test Mass 1
TM 1
12 Sensing Electrodes Housing
CM Actuator / CM Structure
Connector through VE
Optical Metrology
Optical Bench Interferometer OBI
Inertial Sensor Head 2
Inertial Sensor 2
VE
Caging Mechanism (CM) Actuators: GPRM & CMSS
ISUK 2
Test Mass 2
CM Actuator CM Signal Acquisition
Coax Cables
Connector through VE
LCA LTP Core Assembly
Inertial Sensor Front-End Electronics (FEE SAU)
Sensing & Actuation Unit
FEE PCU DC / DC sync 48 MHz from DMU
TM Position & Attitude Control
Actuation, Suspension, & Sensing
Magnetic Sensors and Actuators
2 x 3-axes Magneto-meters
3-axes Magneto-meters
2 Magnetic Coils
Radiation Monitor
Active Disturbance and Sensing of TM Physical Environment
placed at different location around LCA
LCA Assembly & Integration Equipment
Struts, Thermal Shield etc.
Mouting of LCA into S/C and Stabilization
IS Caging Control Unit (CCU)
CM Actuator Contol Electronics FPGA
- Drive Module Motor 1/2 (Position, Force, Motor Speed)
- Feed-back: Position, Status, HK
DC / DC sync 48 MHz from DMU
Caging Mechanism & Control for IS1 & IS2 nominal
CMA: TM Launch Locking, Release & Positioning
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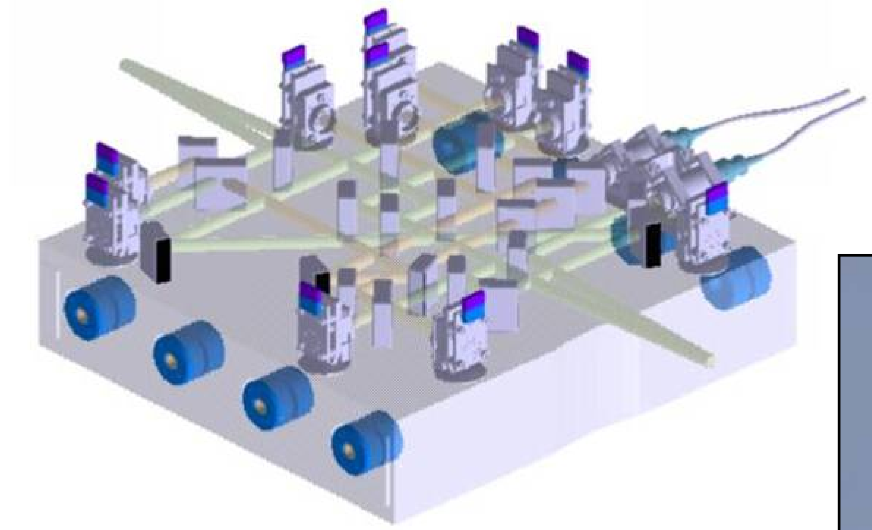
LTP Functional Breakdown

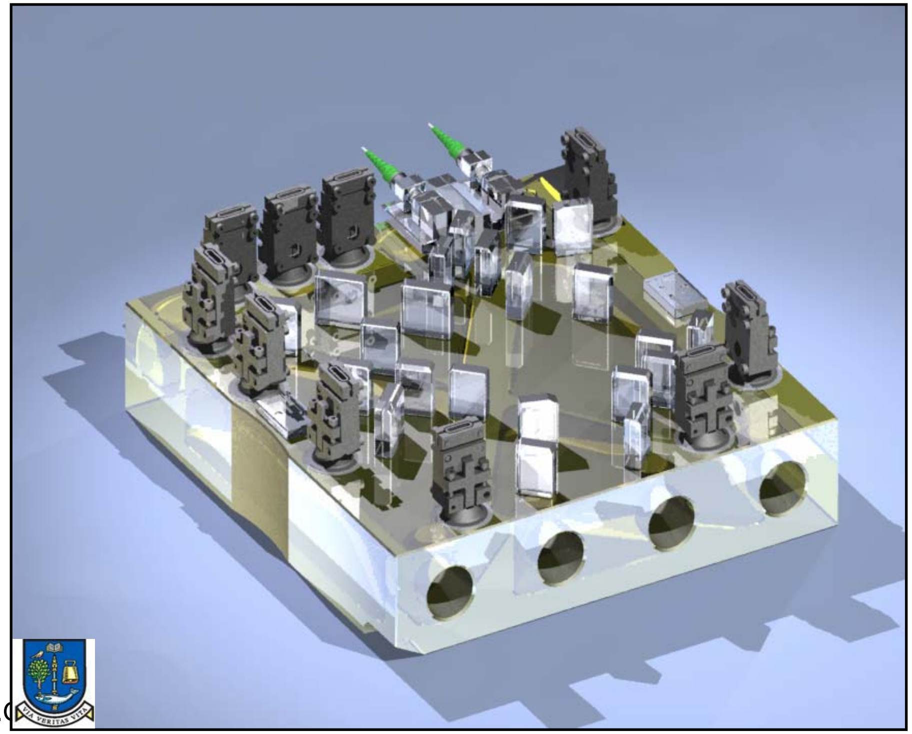
Current Most Risky Technical Items in LTP

1. Caging and Release Mechanism
2. LTP Core Assembly Mounting to Spacecraft
2. Laser Modulator Performance and Qualification
3. Inertial Sensor Housing Vacuum System
4. Inertial Sensor Front End Electronics re-design
5. LTP Performance Verification
6. Software
7. Inertial Sensor / Optical metrology System Alignment Procedure

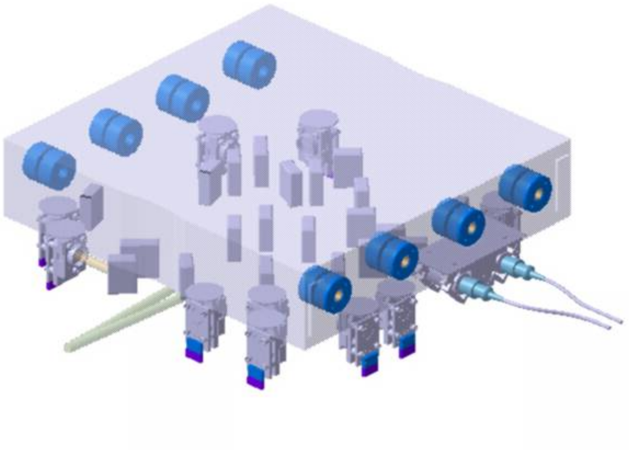
Build-up of the LTP Core Assembly

Start with Interferometer Bench…

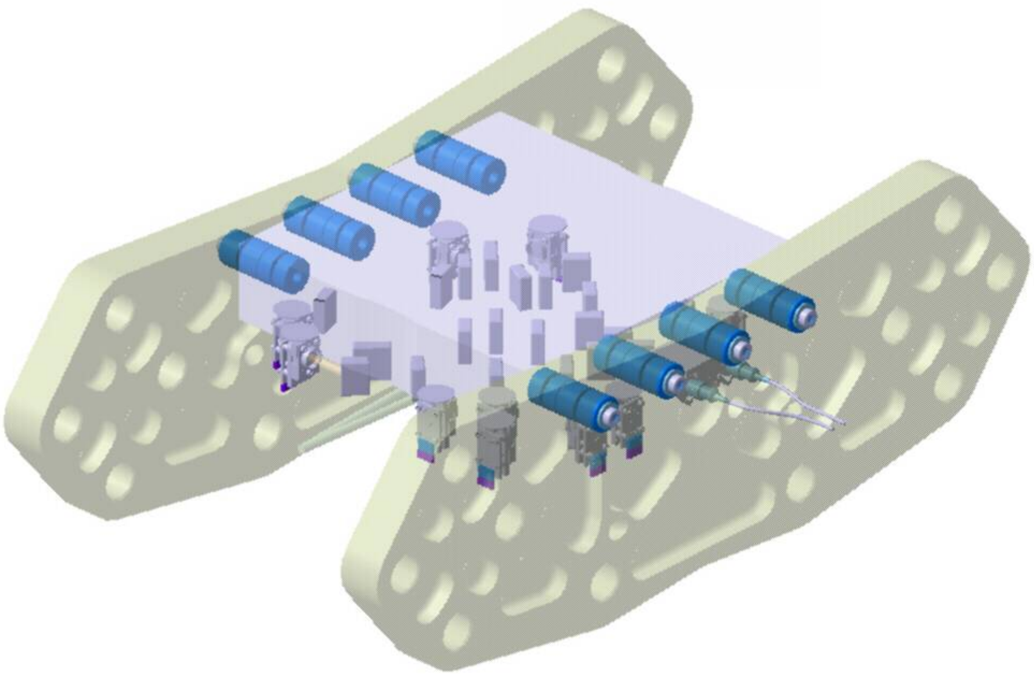




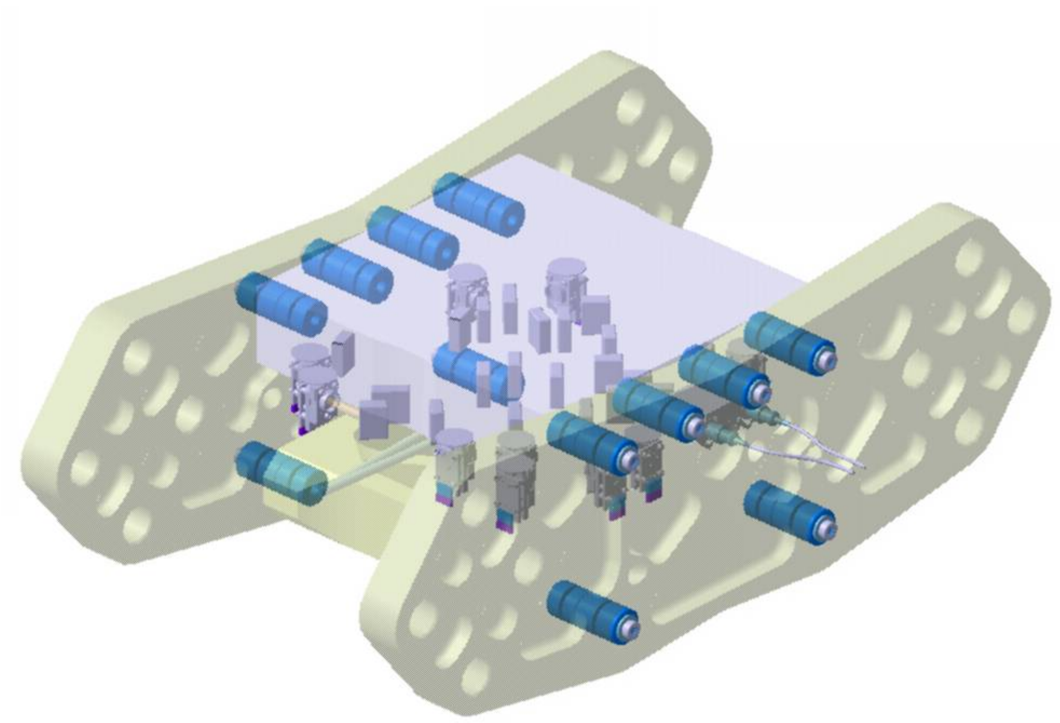
Build-up of the LTP Core Assembly



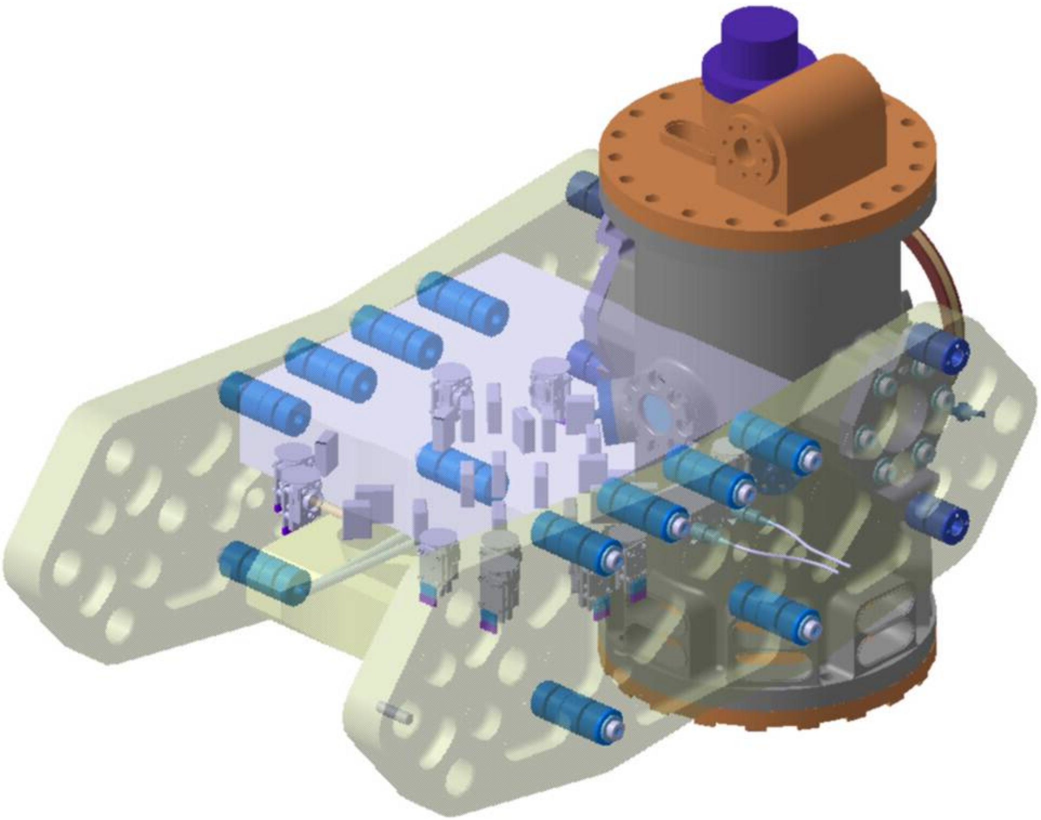
Build-up of the LTP Core Assembly



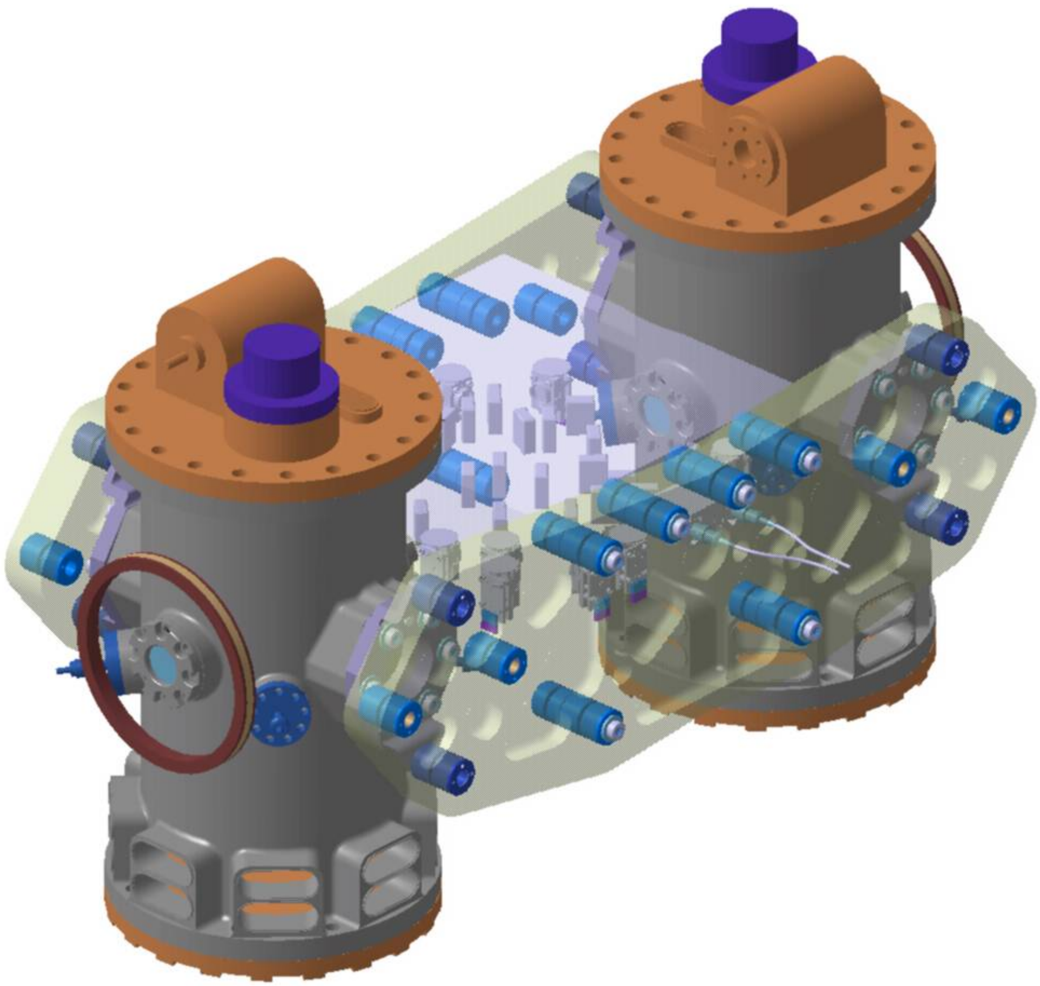
Build-up of the LTP Core Assembly



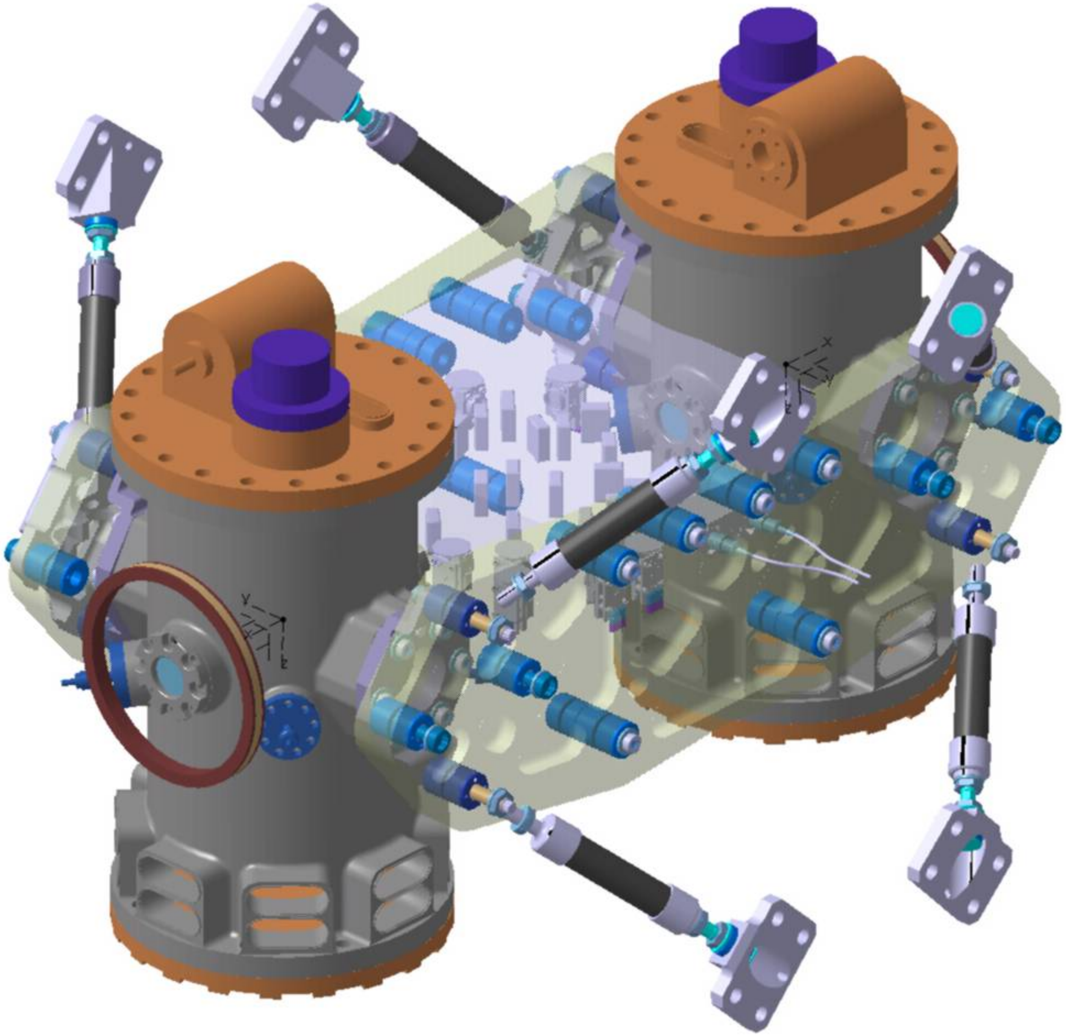
Build-up of the LTP Core Assembly



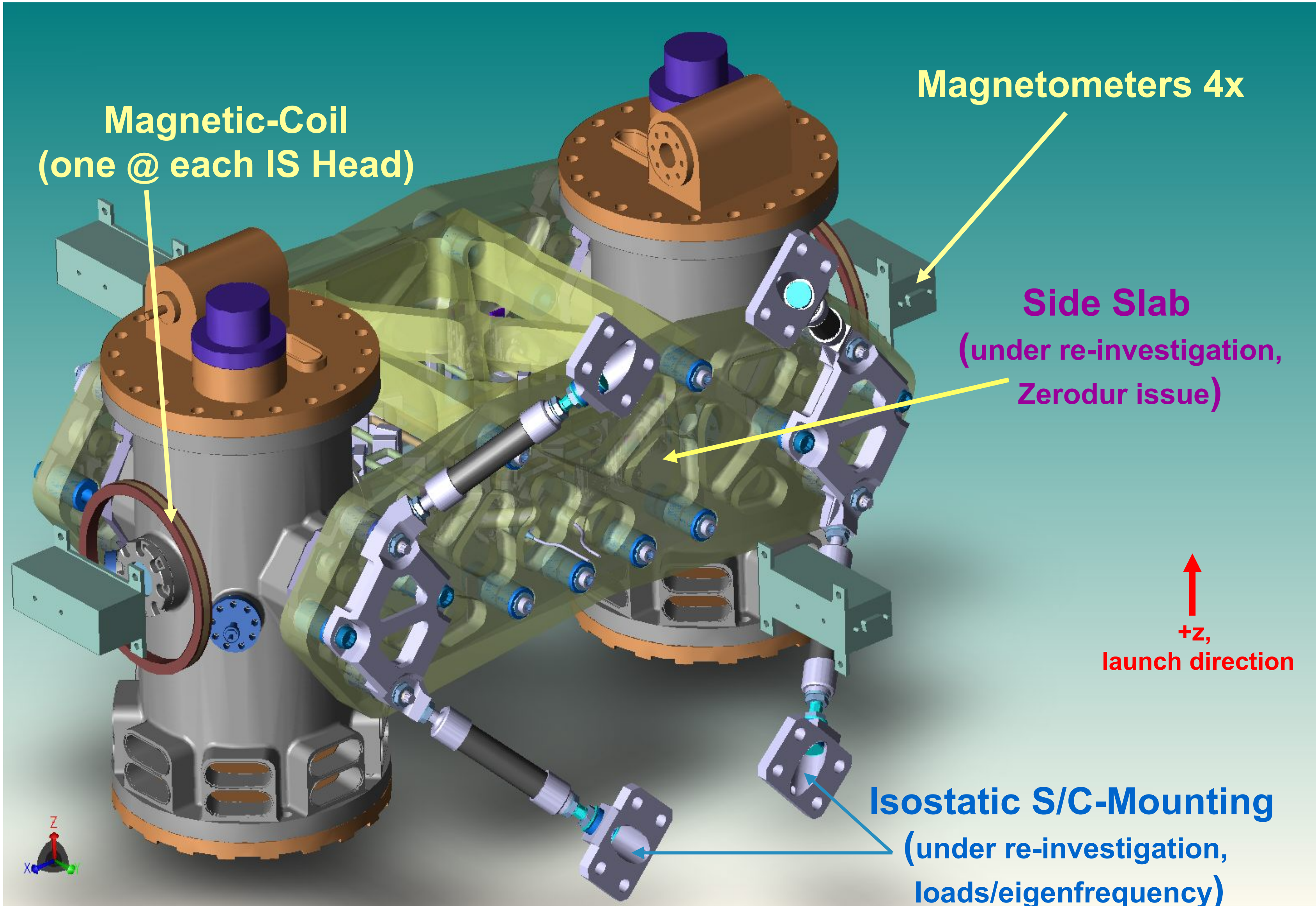
Build-up of the LTP Core Assembly



LTP Core Assembly



LTP Core Assembly Configuration



LTP Accommodation on LISA Pathfinder

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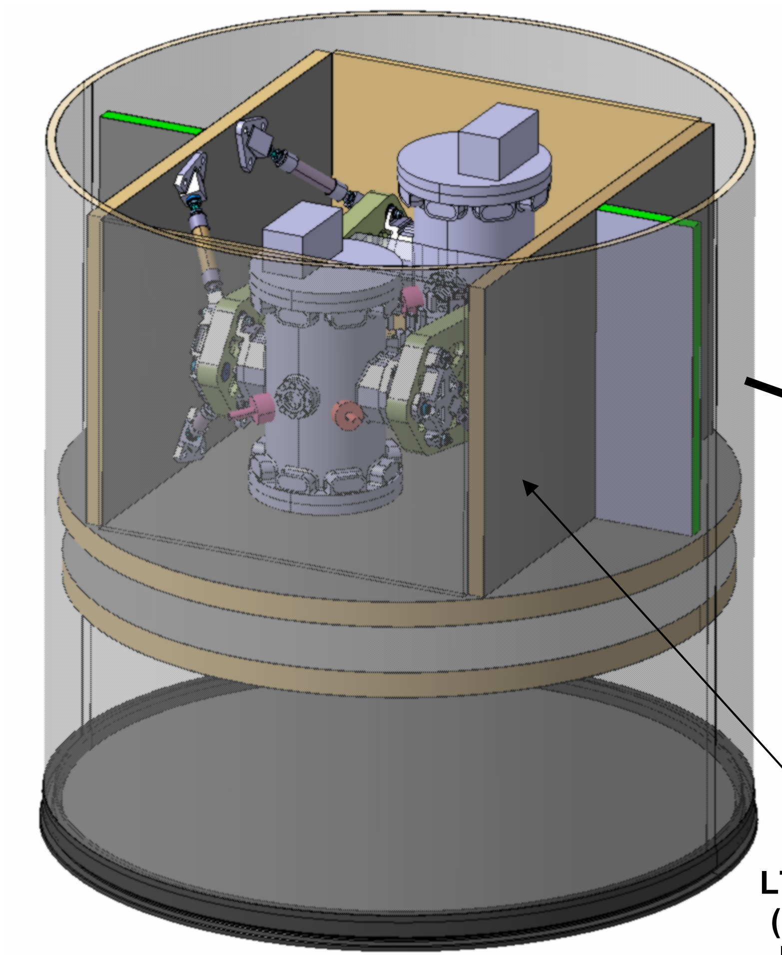
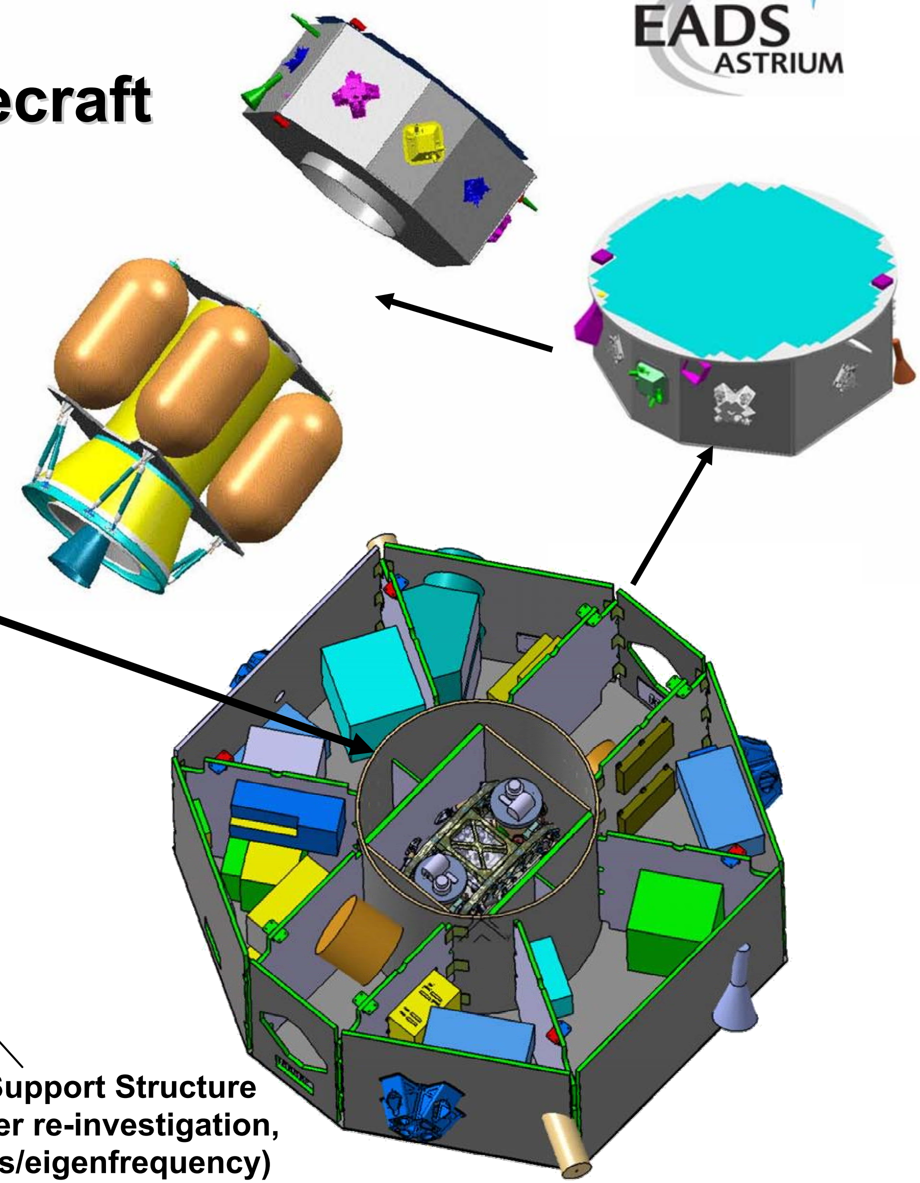
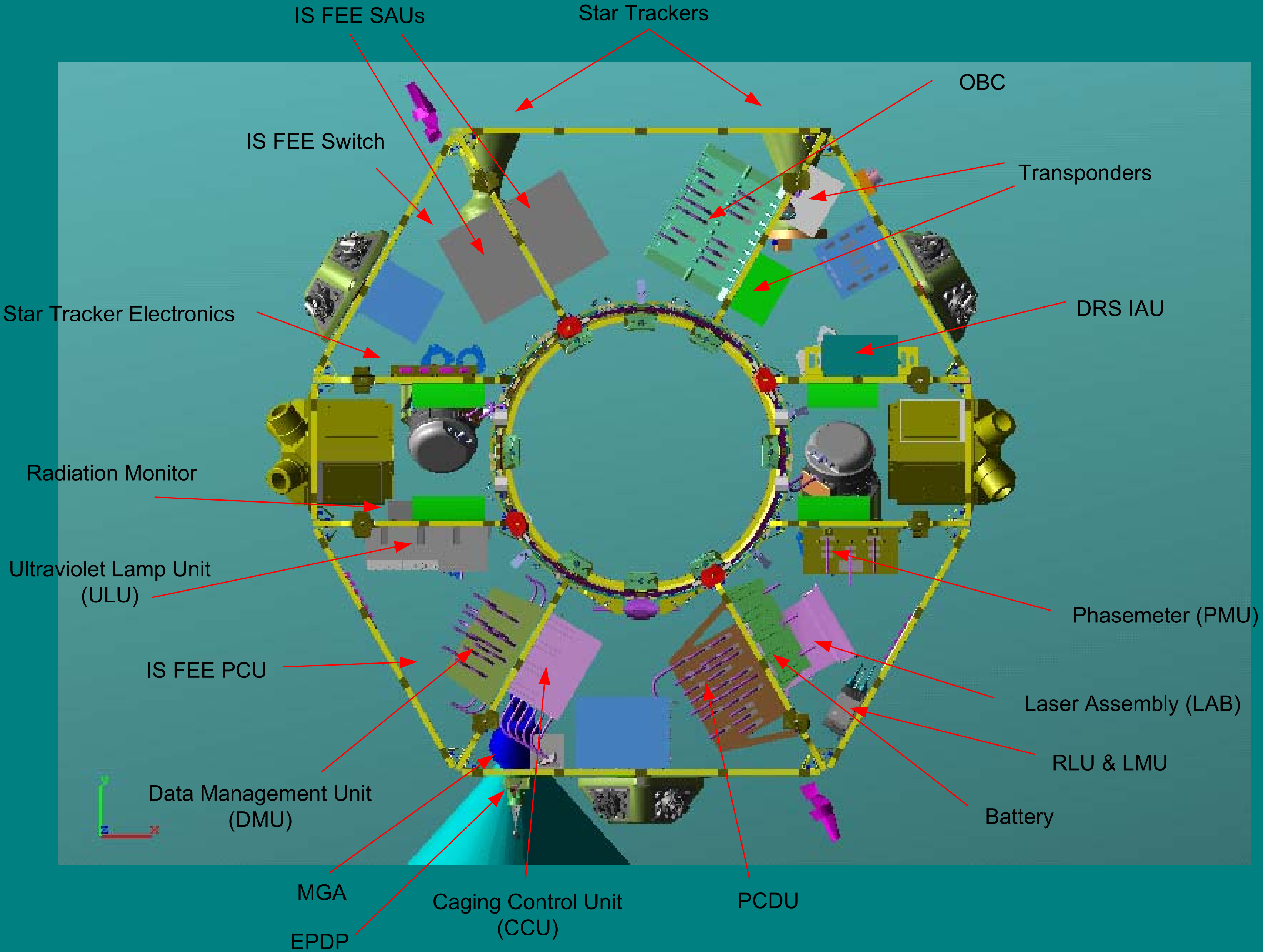
LTP Accommodation on LISA Pathfinder (LPF) Spacecraft



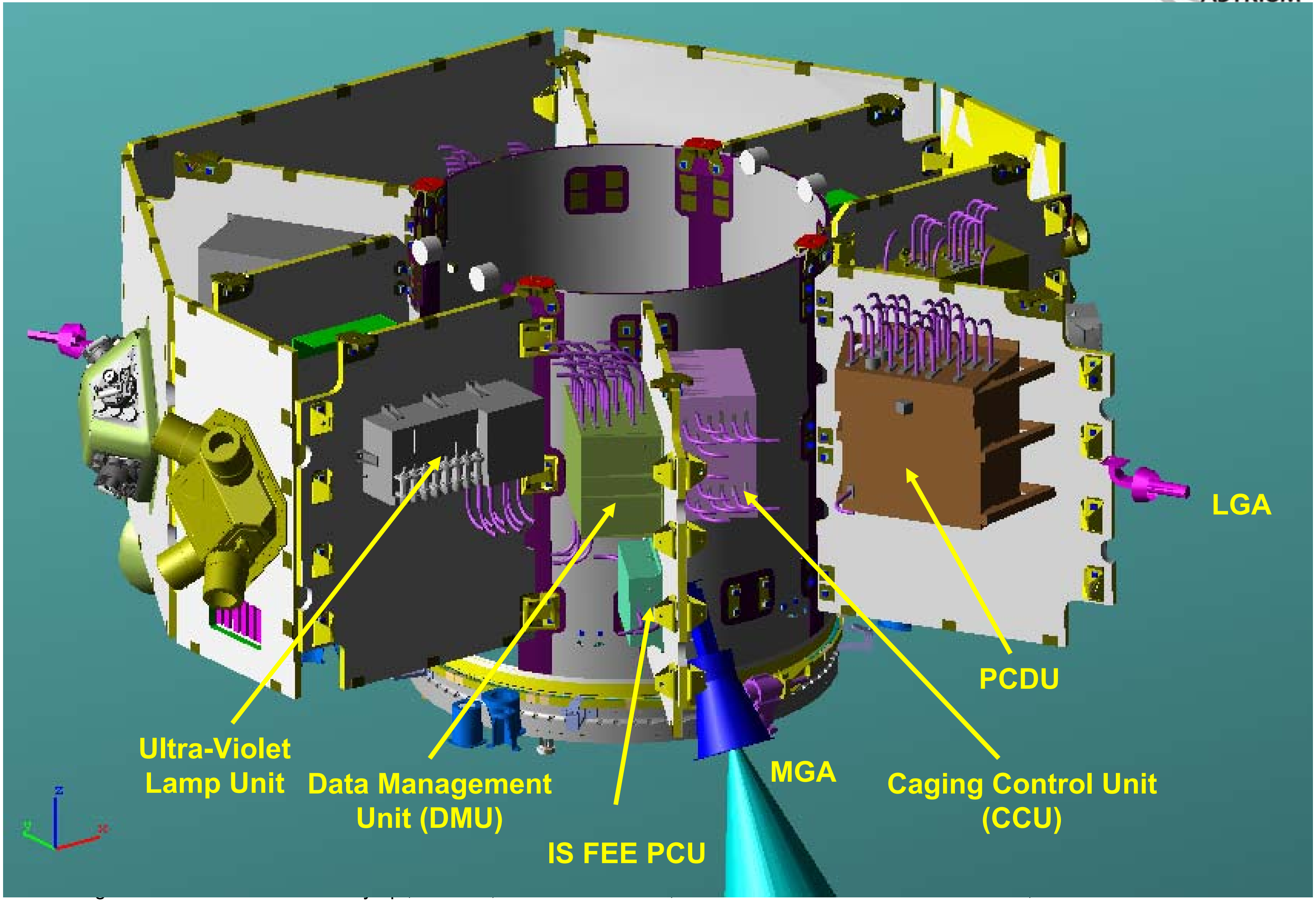


LTP Support Structure (under re-investigation, loads/eigenfrequency)

Accommodation of LTP on LPF Science Module



Internal View –X-Y



Inertial Sensor and Optical Metrology Alignment

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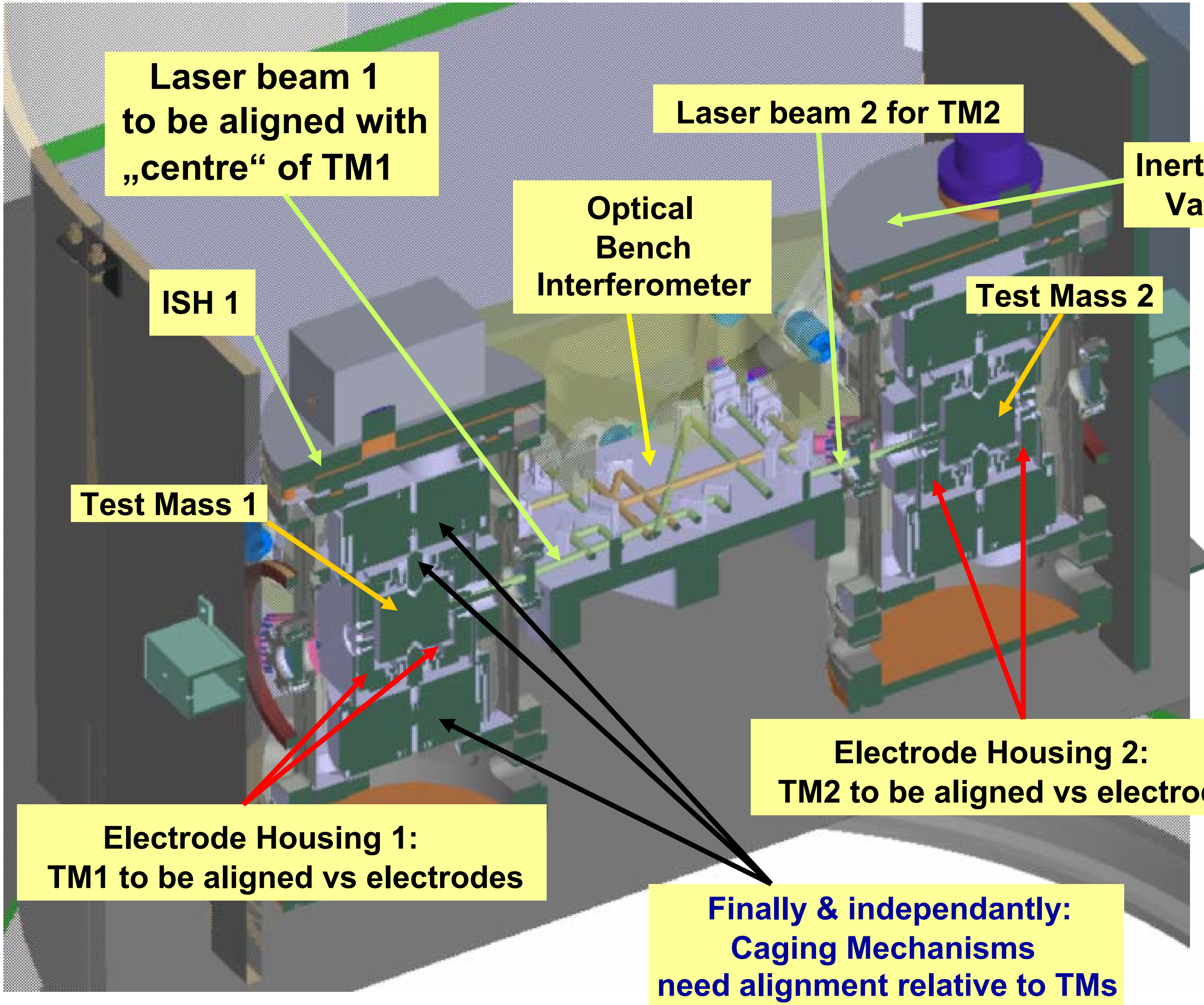
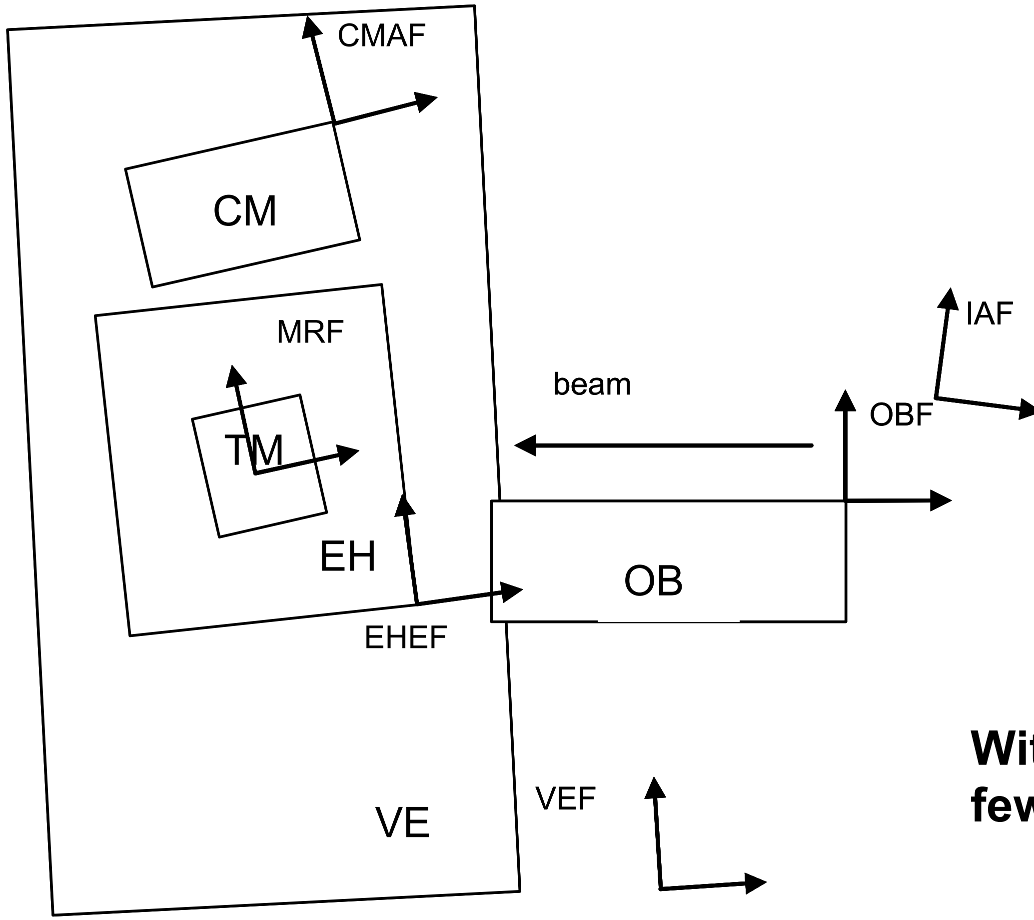
Alignment Task: Items to be Aligned (LTP internal)



Alignment Reference Frames



Within few µm and few µrad accuracy

Test Mass Release by Caging Mechanism

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Caging Mechanism Assembly (CMA)

- **The CMA Release function feasibility is currently the challenge of LTP development.**

- **Demonstration of release feasibility is ongoing and concepts have to be proven by breadboard tests yet**

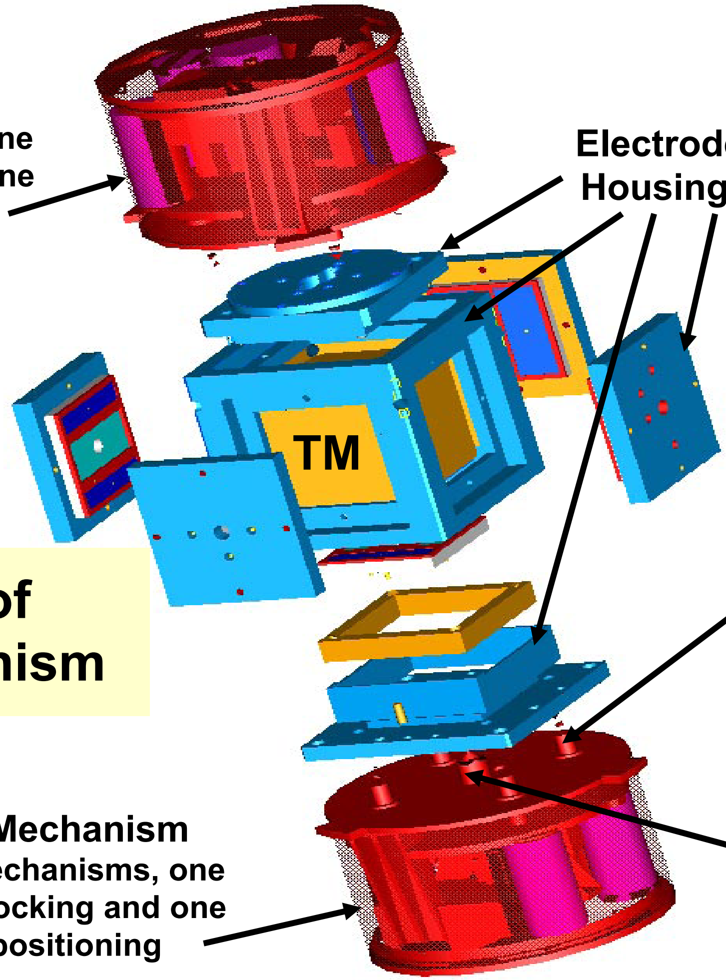
  - **Caging Mechanism SubSystem (CMSS) will hold TM during launch and will release TM from caged position**
    ➔ requires large holding forces up to 3000 N to be applied to a gold-gold contact surface and consequentially strong adhesion forces are to be controlled

  - **Grabbing, Positioning, and Release Mechanism (GPRM) shall release TMs into free fall after TM has been separated from CMSS**
    ➔ requires separation of gold-gold contacts which were exposed to contact forces up to 300 N
    ➔ requires release of the TMs with residual initial velocities suitable for the DFCAS / Front-End Electronics range of control forces

Caging Mechanism (CM) Design Principle

Upper Caging Mechanism
2 nested mechanisms, one for launch locking and one for release/positioning

Electrode Housing



CMSS Fingers (4)
supporting Test Masses during Launch and Ground Handling

Schematics of Caging Mechanism

Lower Caging Mechanism
2 nested mechanisms, one for launch locking and one for release/positioning

GPRM Plunger
(shown recessed)

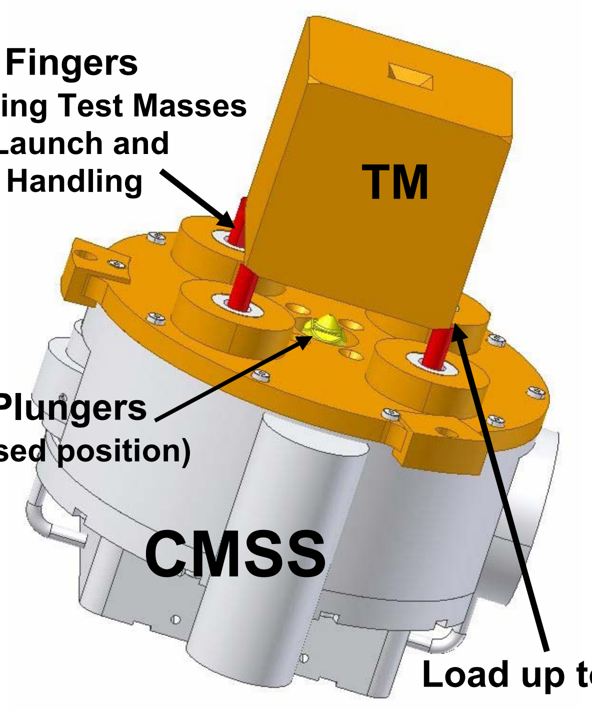
Note: Image shall demonstrate principle but is not up to date in design details

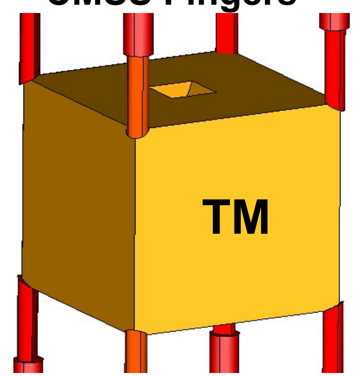
CMA Critical Issue

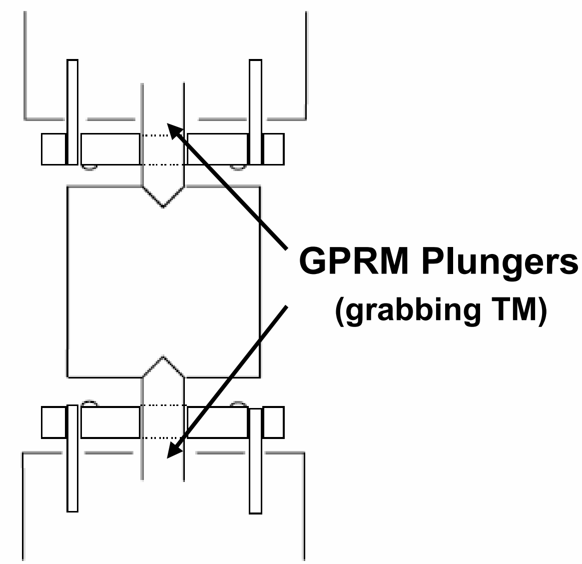
Demonstration of release feasibility and reliability

- **Caging Mechanism SubSystem (CMSS) - holding of TM for launch and release from caged position**

- **Grabbing, Positioning, and Release Mechanism (GPRM) - release of TM into free fall after TM has been separated from CMSS**







TM held in center position by the GPRM

LTP Operations:
Caging Mechanism Control Process

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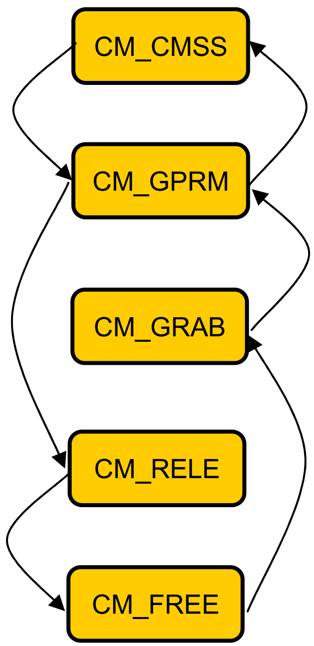
LTP Operations:
Caging Mechanism Control Process

- ☐ **Functionalities modeled**
  - **TM caged by CMSS**
  - **TM held/positioned by GPRM**
  - **TM grabbed**
  - **TM released**

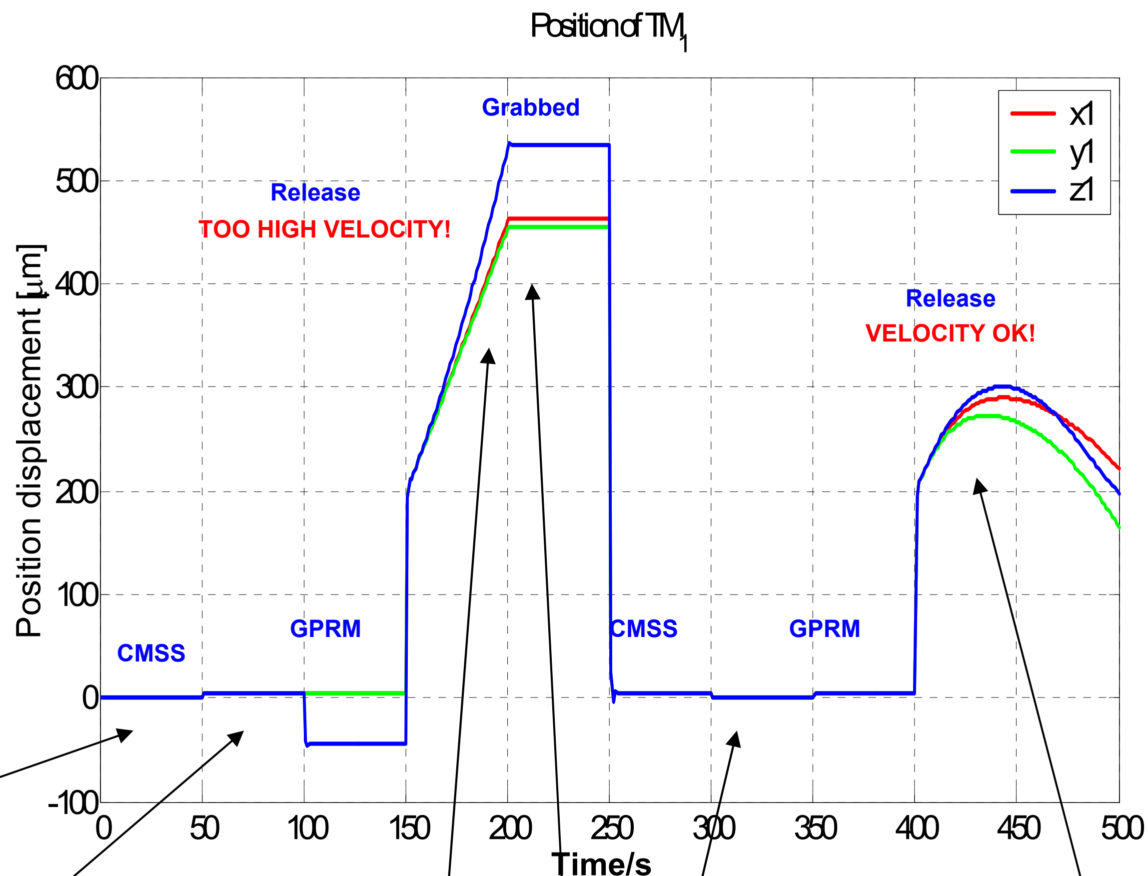
- ☐ **The model is interfaced with:**
  - **IS sensing/actuation**
    - plunger in contact
    - electrical field variation
  - **DFACS**
    - release/positioning commands
    - TM velocity estimation for automatic grabbing/recaging



LTP Operations:
Caging Mechanism Control Process

Detailed simulation of process

An Example



Caging release

Grabbing release

DFACS Sensor detects position and speed

Again!

Release ok!

Failed!-> regrab

LTP Operations:
Caging Mechanism Control Process

- ☐ **Release Procedure**
  1. **Fast&Short Retraction GPRM Plungers**
  2. **Check TM velocity < Threshold**
  3. **YES → Full retraction GPRM Plungers**

     NO → Recage, Repeat Procedure

- ☐ **Simulation Setup @ TM Release**
  - Velocity $5 \cdot 10^{-6}$ m/s - $1 \cdot 10^{-4}$ rad/s
  - Displacement 200 m - 2 mrad

- ☐ **Transient time**

  TM centered within 600 sec

- ☐ **Overshoots**

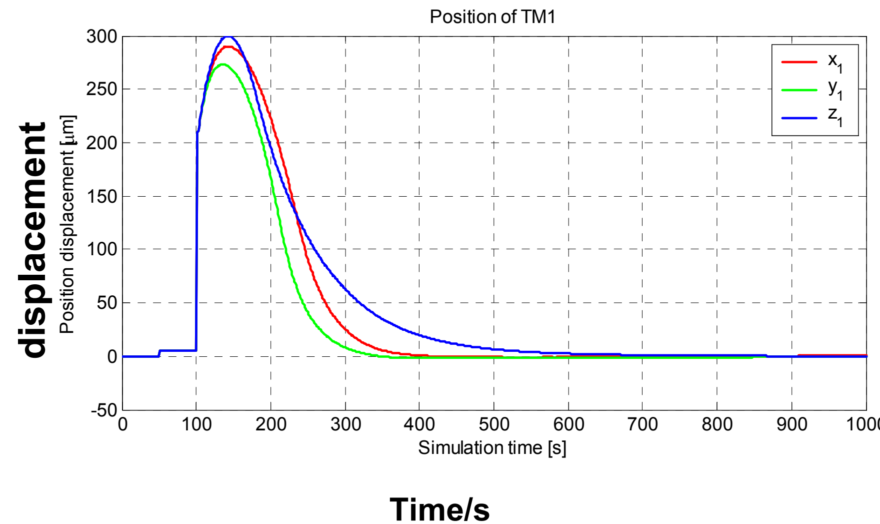
  < 100 m, < 2 mrad

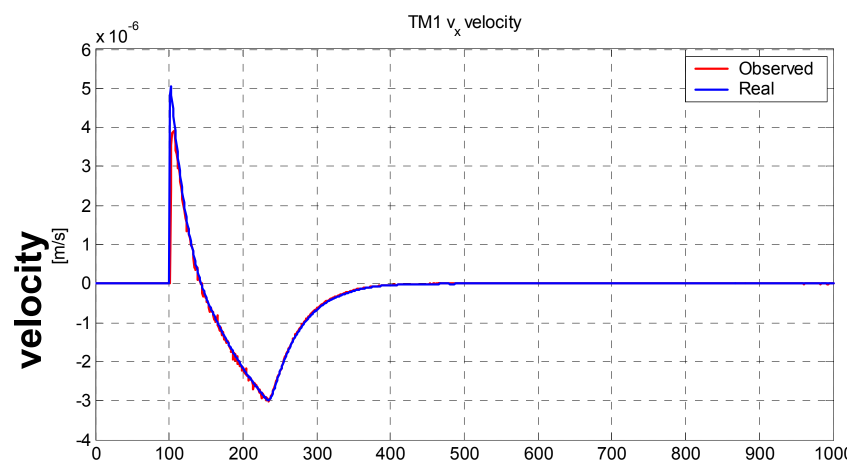
- ☐ **TM steady state accuracy (3σ)**

  < 2 m, < 40 rad

- ☐ **TM velocity estimation**

  Reliable estimation (<10% error) provided to the CMA within 6 sec





LTP operations: Optical Metrology Acquisition

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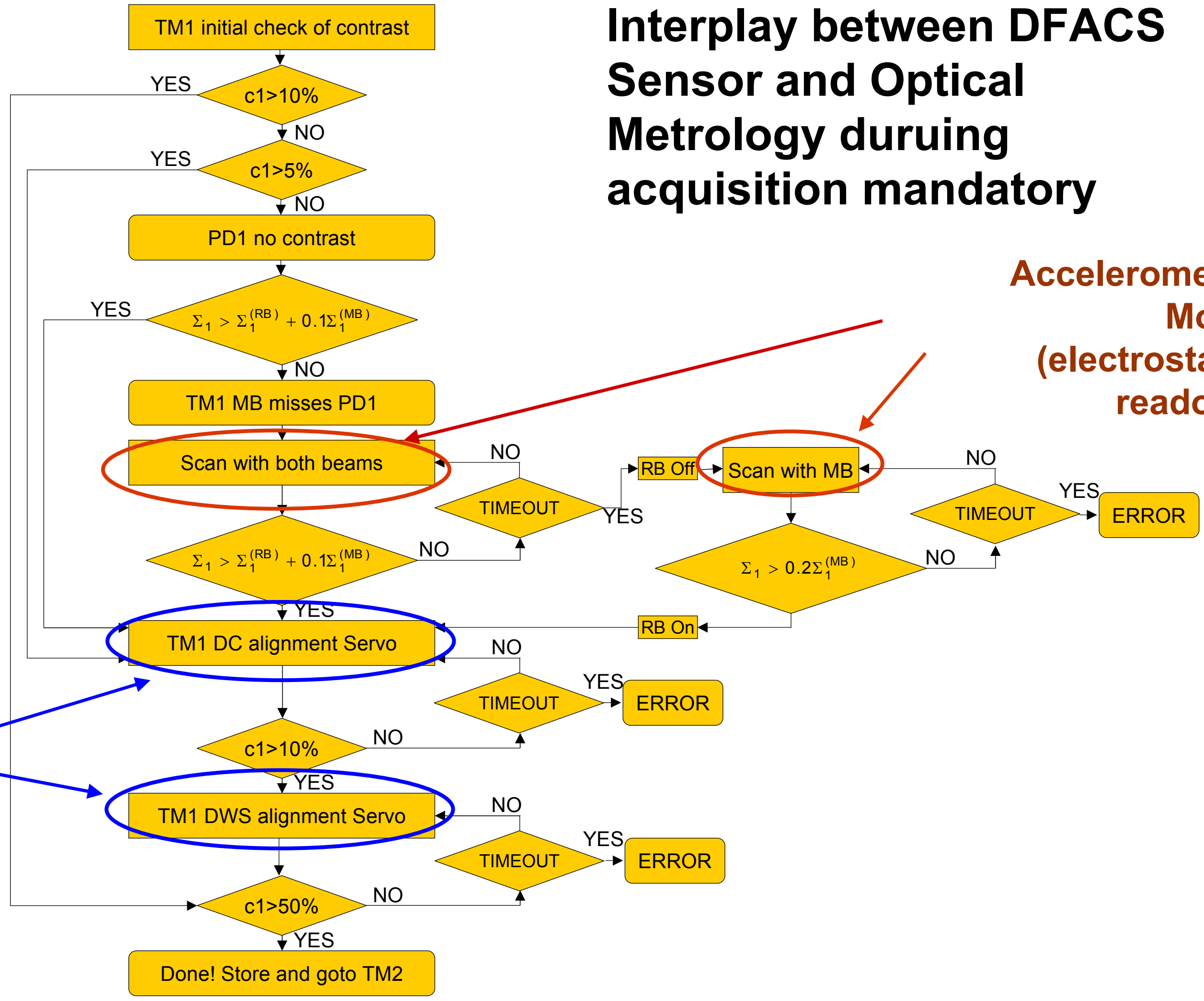
Acquisition sequence



Interplay between DFACS Sensor and Optical Metrology duruing acquisition mandatory

Accelerometer Mode (electrostatic readout)

Accelerometer Mode (optical readout)

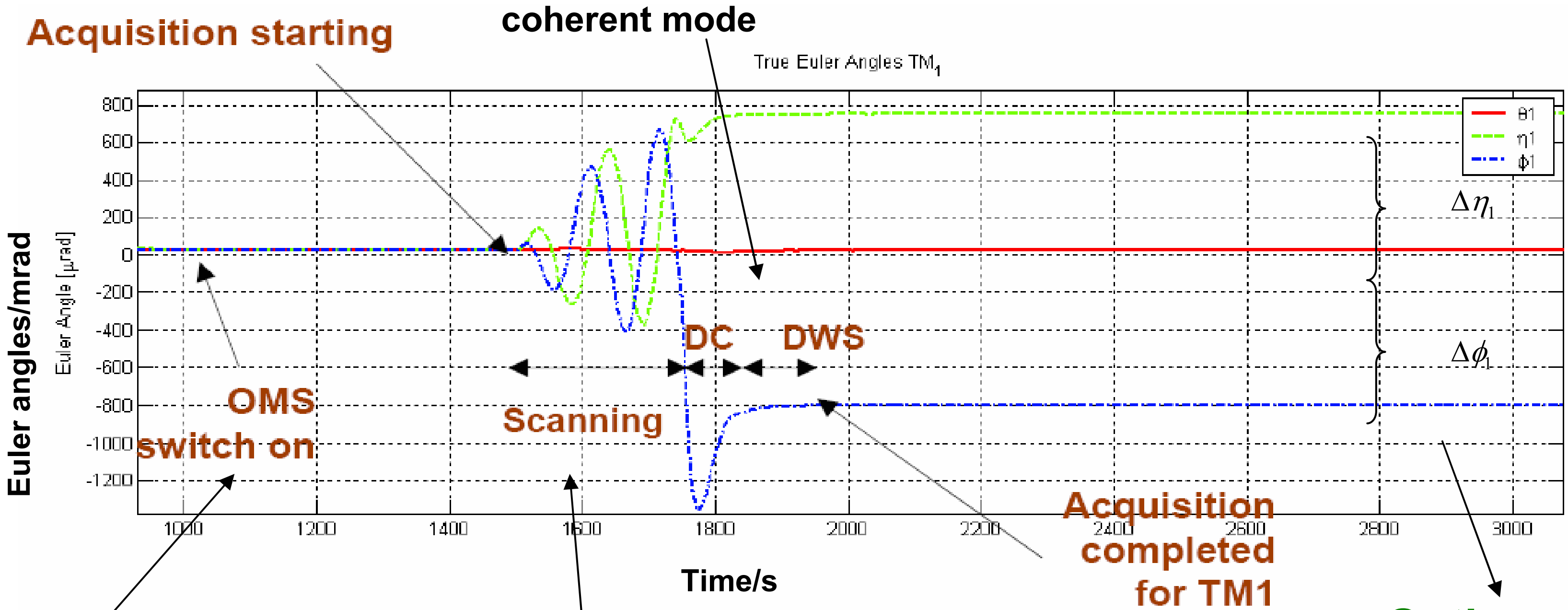
Simulation results (E2E)

- **Actual Euler angles (IS1 frame) for TM1:**

EHF angularly misaligned w.r.t. IFO by:

$$\left\{ \begin{aligned} \Delta\vartheta_1 &= 0.4\text{mrad} \\ \Delta\eta_1 &= -0.75\text{mrad} \\ \Delta\phi_1 &= 0.8\text{mrad} \end{aligned} \right.$$

4Q diode detects beam, enters coherent mode



DFACS Sensor and optical Metrology on

TM attitude spiral scan

Start with TM2

Optimum for capacitive sensing

LTP Operations:
Charge Management Control Process

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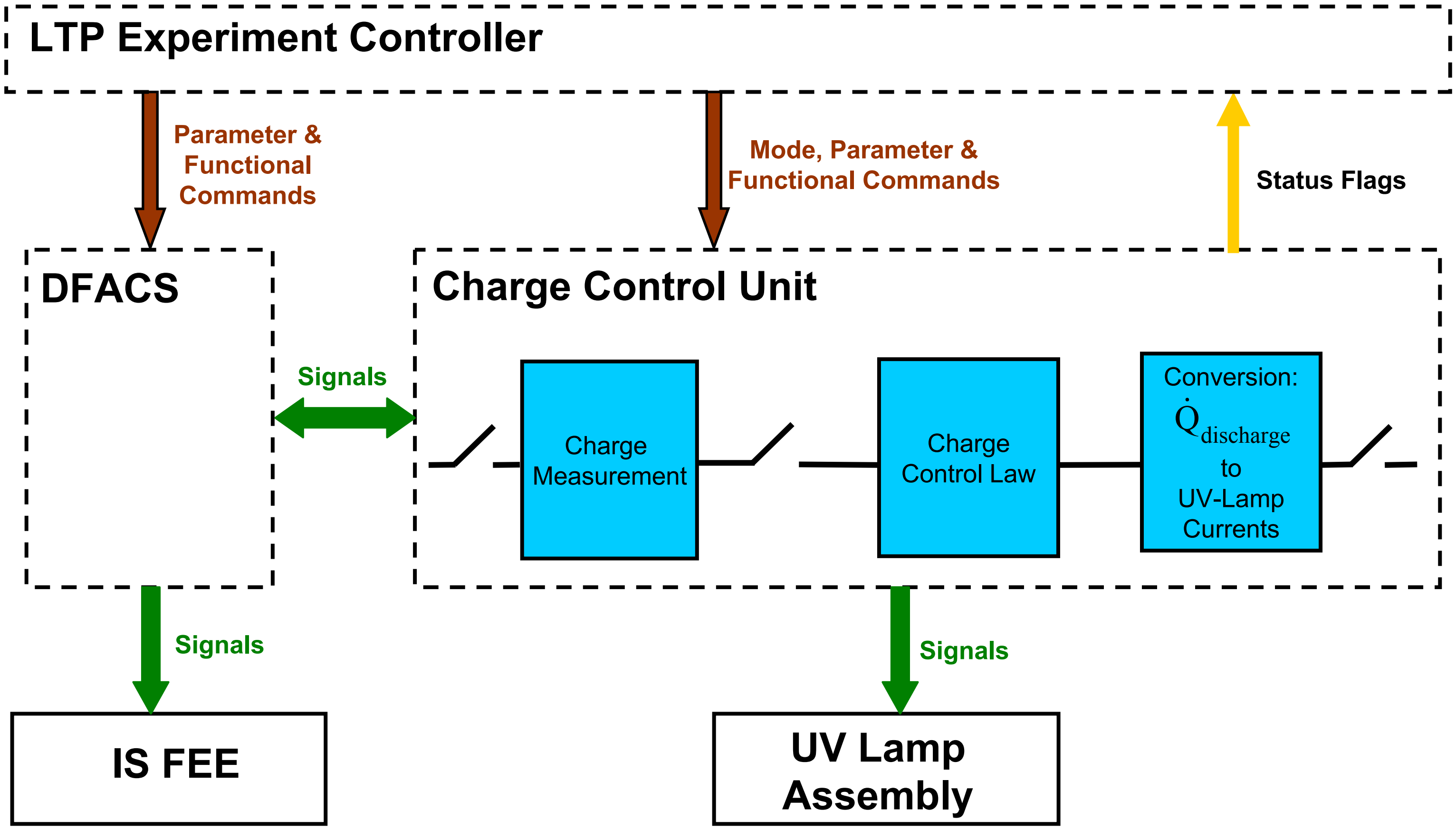
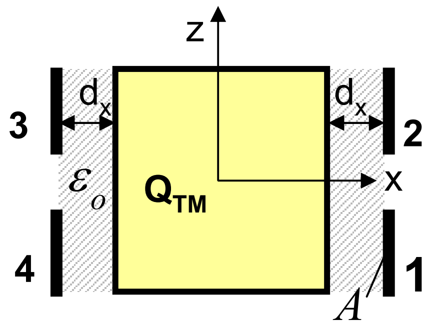
Charge Management Control Process
Top-Level Architecture



Charge Management Control Process
Principle of Charge Measurement

Goal: Determine Charge on TM (illustrated for measurement along x)

Apply Oscillating Voltage with Proper Phase to Electrodes 1-4:



$V_1 = V_2 = B \cdot \sin(\omega \cdot t + \pi)$

$V_3 = V_4 = B \cdot \sin(\omega \cdot t)$

Force Proportional to Charge is Generated: $F_x^Q(t) = -\frac{4 \cdot \varepsilon_o \cdot A}{c_{tot} \cdot d_x^2} \cdot Q_{\mathrm{TM}} \cdot V_1(t)$

- Equal electrodes, no dc voltage, and constant d_x assumed
- Sinusoidal force with same frequency and phase as V(t) produced

Force not Directly Measurable, but Displacement: $x^Q(t) = \frac{F_x^Q}{m_{\mathrm{TM}} \cdot (2\pi f)^2}$

Finally: Estimate Charge out of Measured Signal $x^Q(t)$

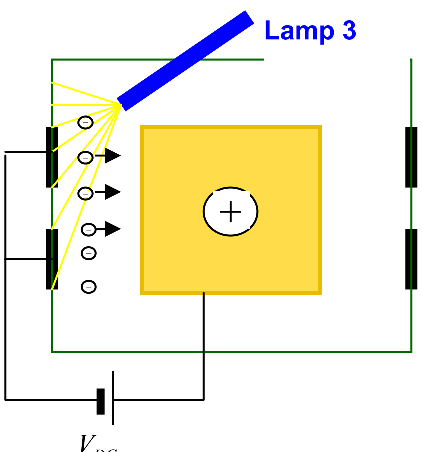
- Data-recursive estimation algorithms used for online estimation

Charge Management Control Process
Charge/Discharge Control

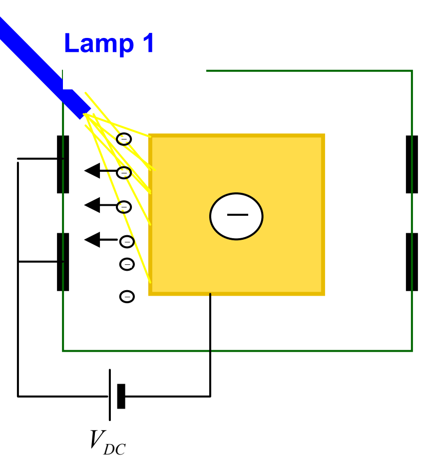
- **Discharge Rate Depending on:**
  - **Commanded UV Lamp Current I_{UV}**
  - **Potential Difference between TM and EH → Apply Bias Voltage V_{DC} to Enhance Discharge**

- **Constraint: Max. 2 UV Lamps can be Used at Same Time**
  - **One Lamp per TM for simultaneous discharging**

- **Positively charged TM**
  - **Illuminate EH (Lamp 3 or 4)**
  - **V_{DC} such that V_{TM} positive**



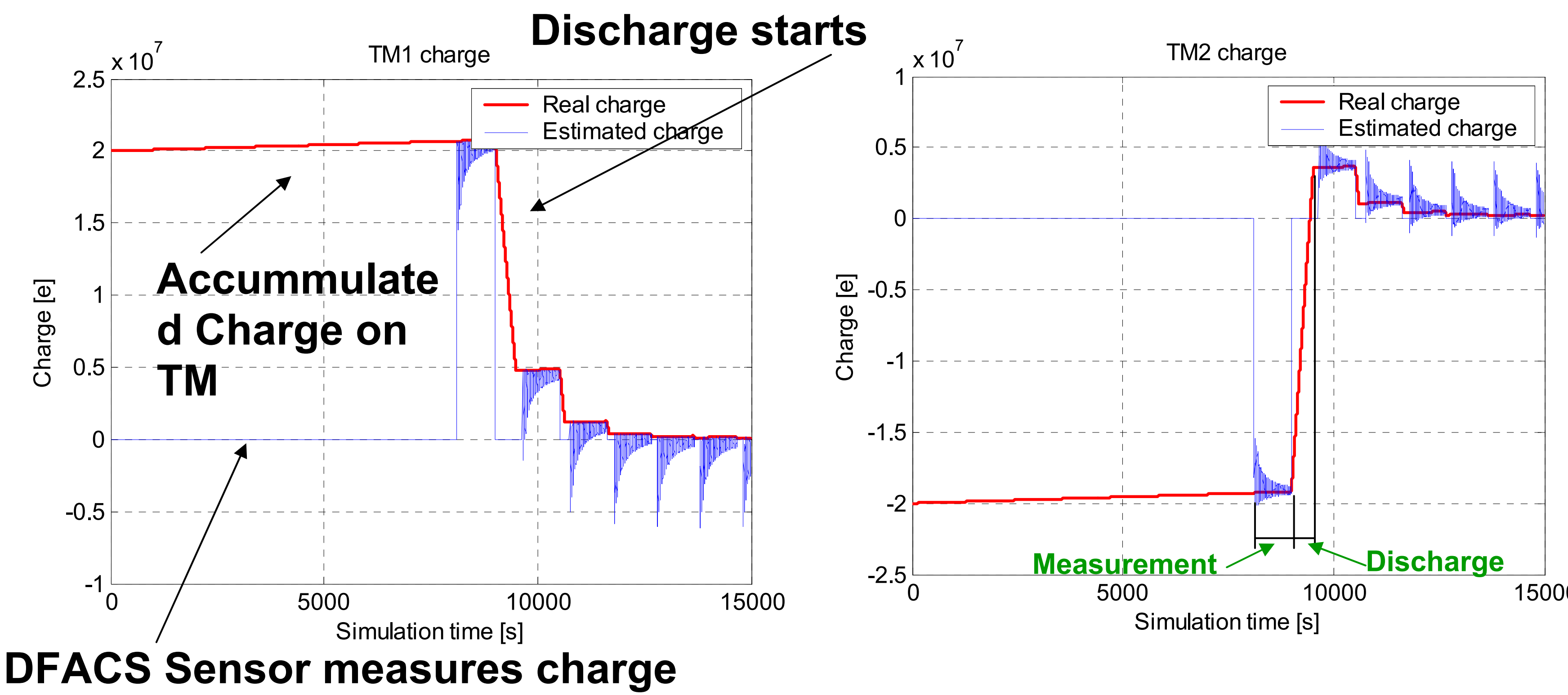
- **Negatively charged TM**
  - **Illuminate EH (Lamp 1 or 2)**
  - **V_{DC} such that V_{TM} negative**



Charge Management Control Process
Fast Discharge Results (based on ICL model)

- **Control Accuracy:** $Q_{TM} < \pm 1 \cdot 10^5 e$
- **Duration: 3 Charge Estimation/Discharge Cycles Required**

Less than 4000 sec for Fast Discharging of Both TMs



LTP operations:
Optical Metrology Acquisition

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Summary

- Astrium has to manage a "can of worms" and has to forge together heterogeneous preparatory work
- Current critical issues identified and mitigation on-going
- Close interaction of DFACS modes development, LTP performance engineering and LTP hardware development most critical
- Initalisation of operation modes well understood and verified in simulation