Drag-free control of LISA Pathfinder

M Hewitson for the LPF team
GEO sim+control meeting, May 6th 2011

Contents

- 3 bodies
- 18 degrees of freedom
- show which sensors
- describe the control scheme

What’s the point of it all

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- To place a body in a 'pure' geodesic motion
  - place a test-mass in space
  - shield it from external disturbances (with a SC)
  - SC should follow the TM without being in contact
    - minimise the SC-TM forces

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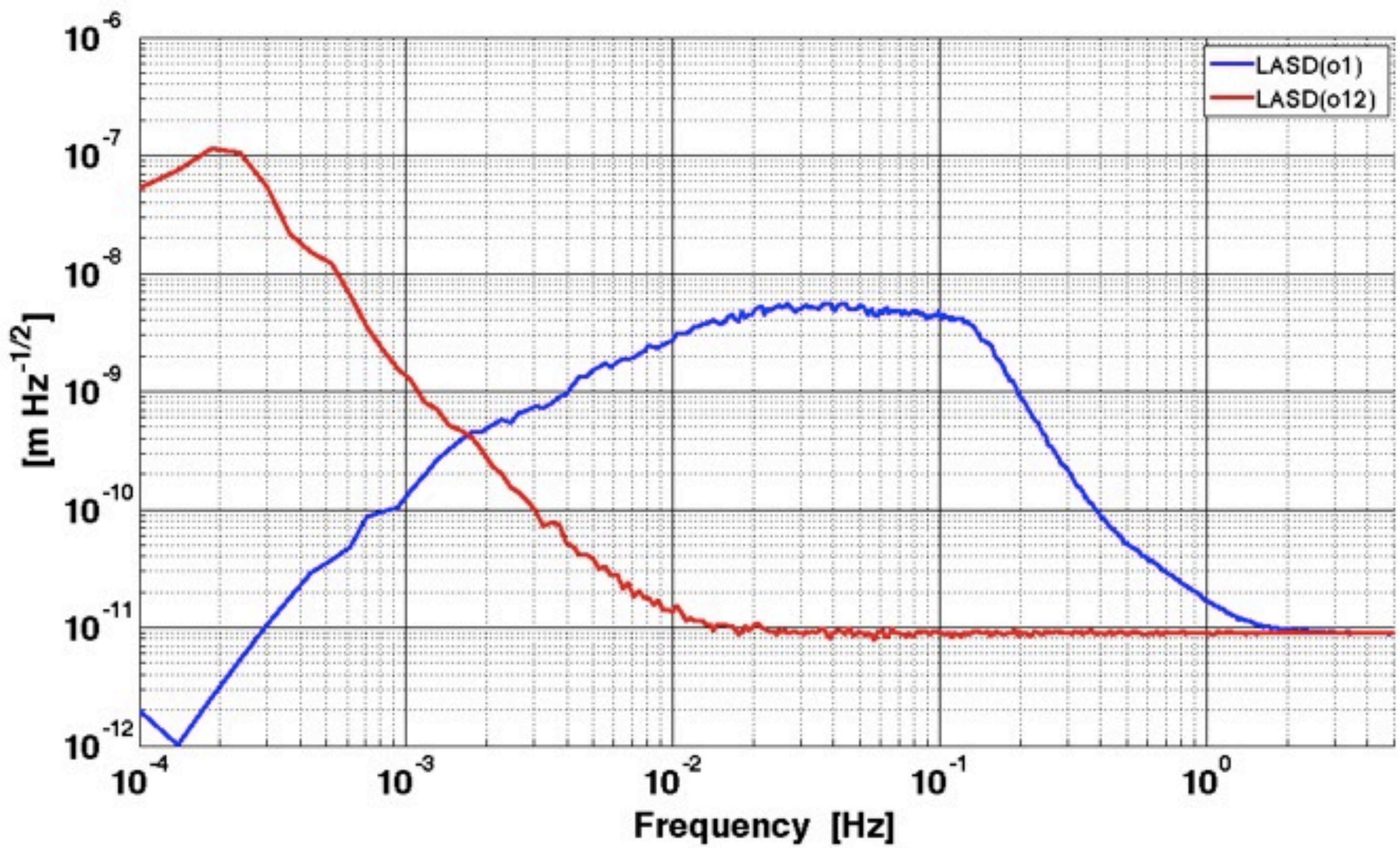
- To place a body in a 'pure' geodesic motion
  - place a test-mass in space
  - shield it from external disturbances (with a SC)
  - SC should follow the TM without being in contact
    - minimise the SC-TM forces
- How can we assess the 'goodness' of the geodesic motion?
  - use another test-mass as a quiet reference from which to measure the motion of the first
  - second test-mass must follow the first

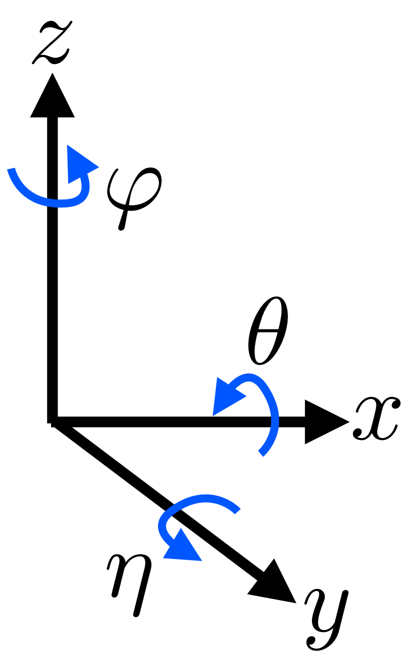
System characteristics

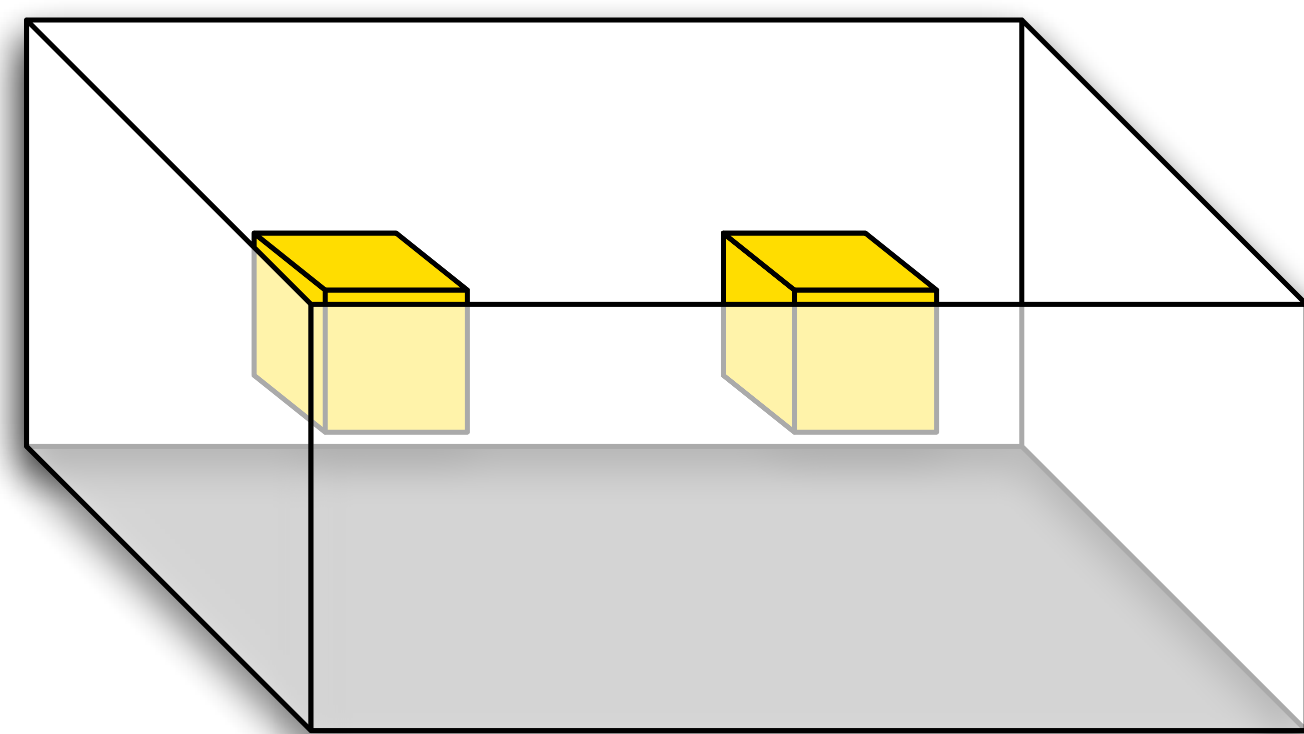
- Low frequency!
  - make measurements around 1mHz
  - experiments take a long time
  - data sampled 10Hz or less



LPF bodies

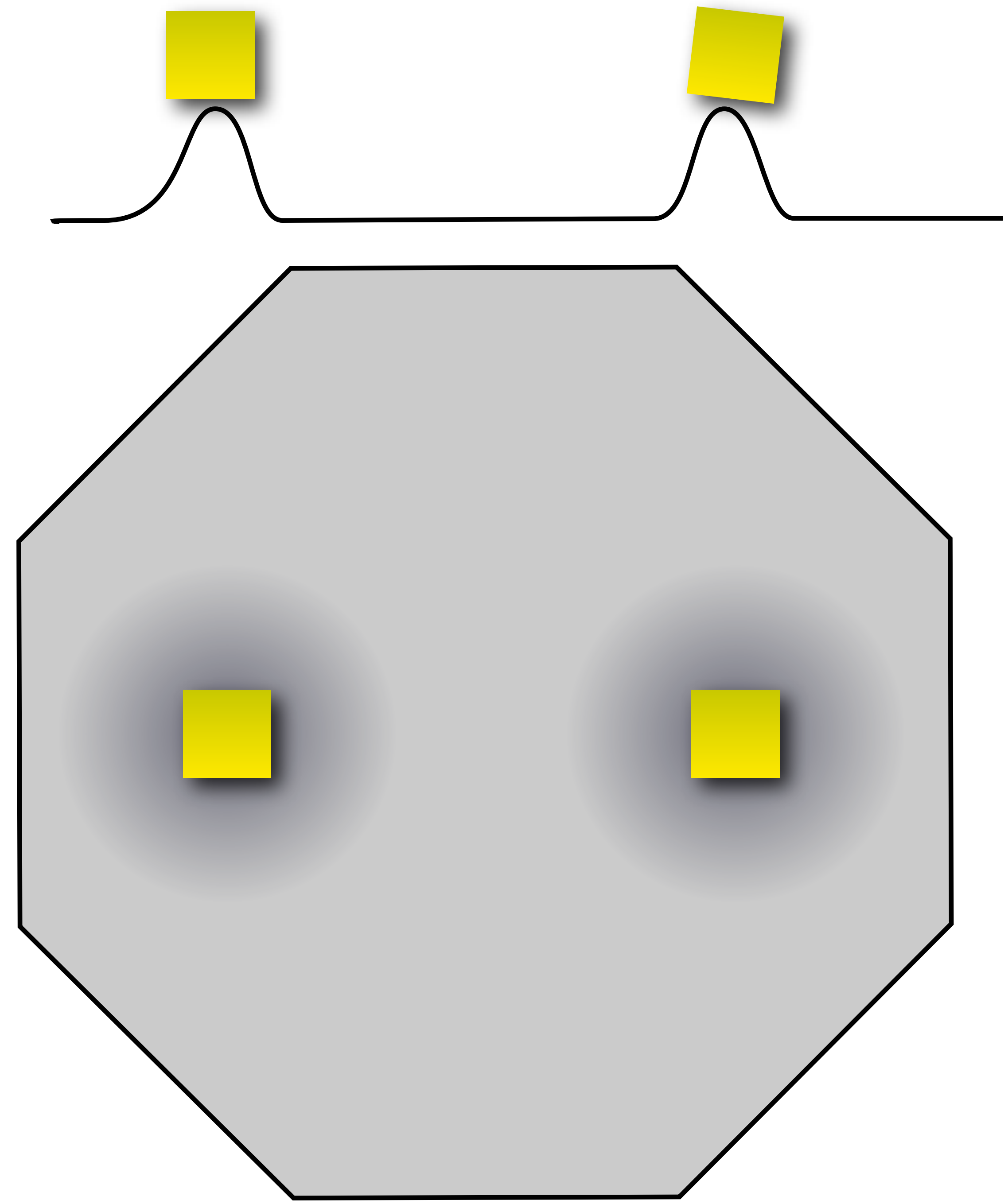
- 3 bodies
- 18 degrees-of-freedom
- Control 15 degrees-of-freedom





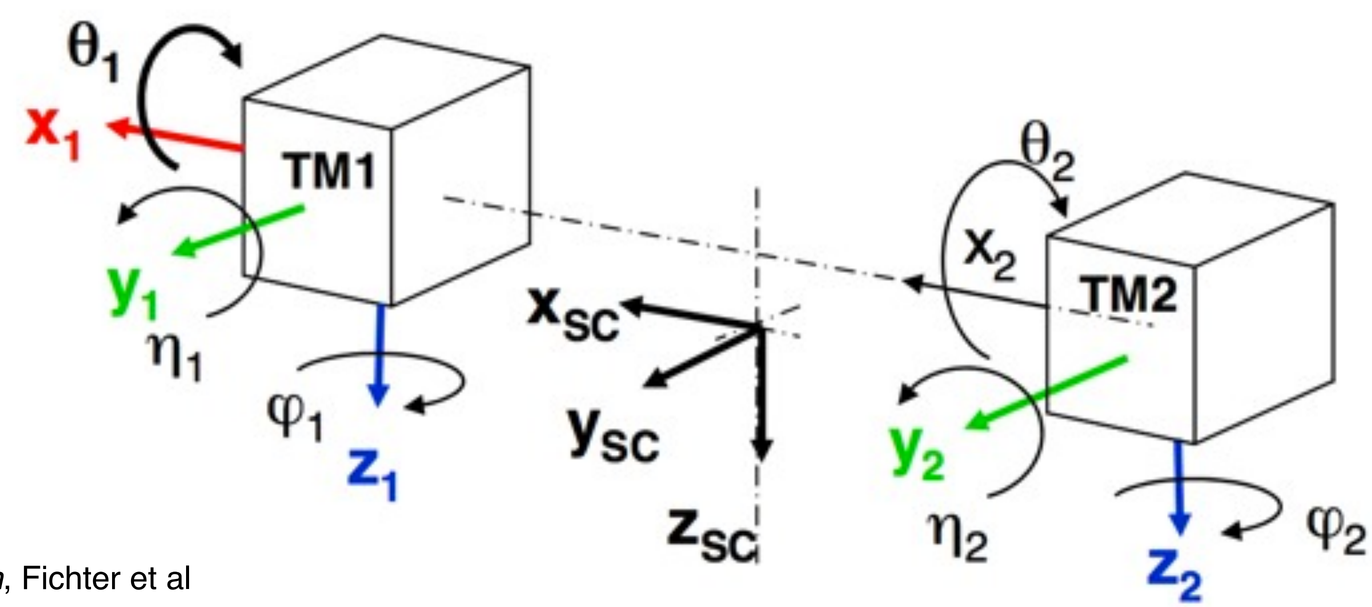
Force gradients

- Need gravitational balancing to minimise dc forces
  - expected level ~10^{-9} m s^{-2}
- Residual dc forces need to be compensated for electrostatically



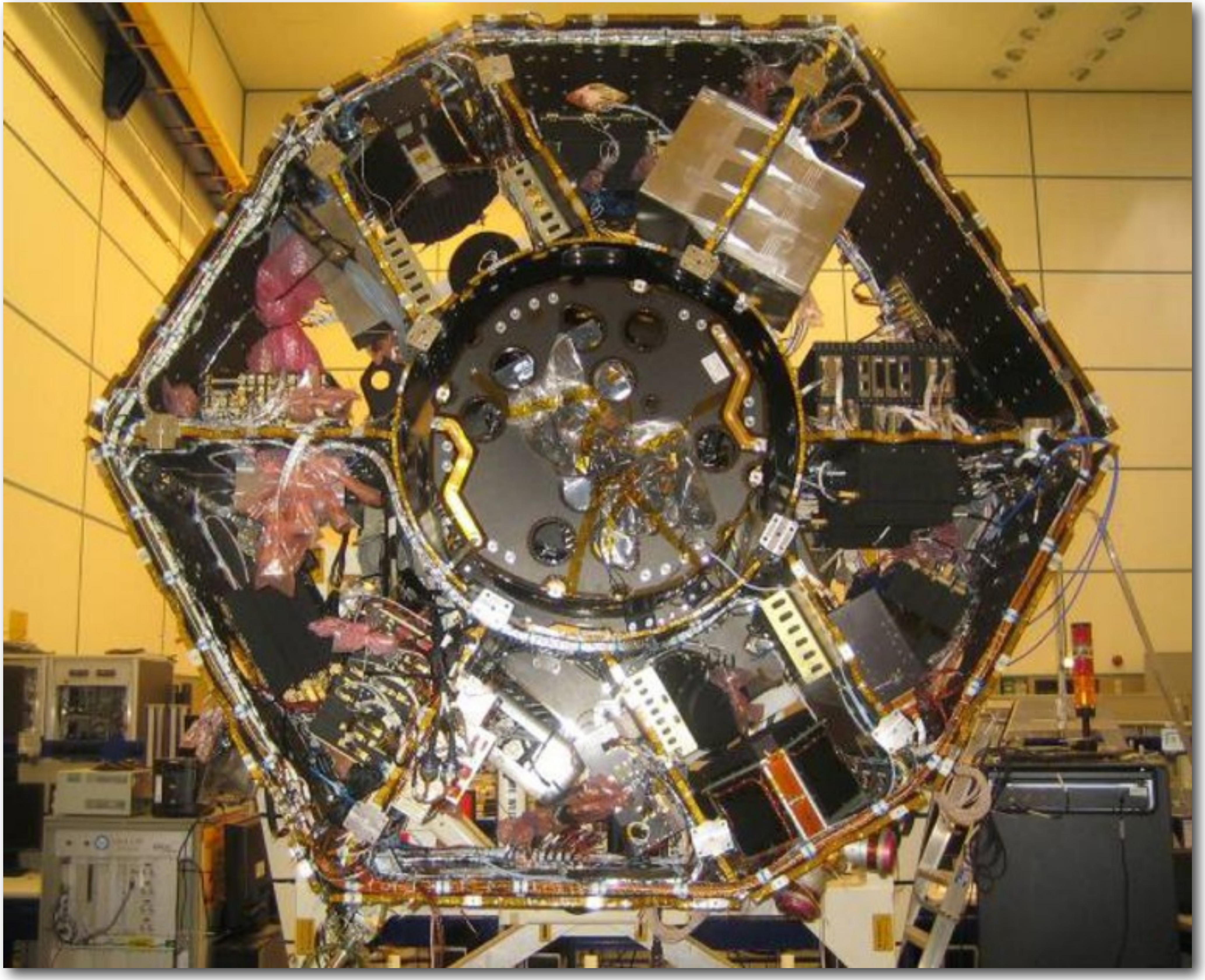
Unstable Dynamics

- Residual effects like self-gravity and magnetic effects produce a spacial force gradient
- This produces a stiffness for the TMs which can be negative
  - unstable test-mass dynamics
- So we need to control the positions and attitudes of the TMs
- Bias control voltages creates additional stiffness

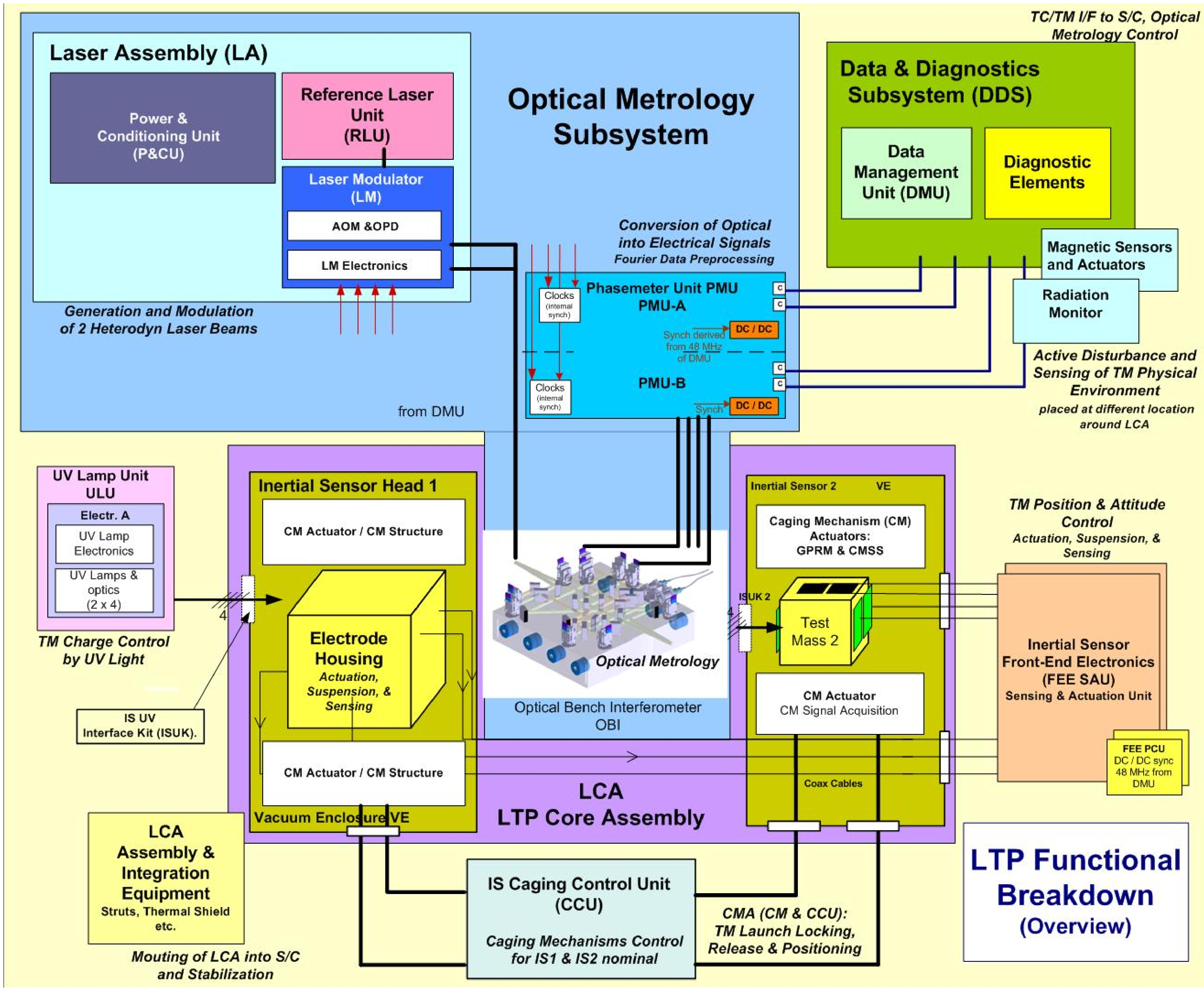


Closed Loop Performance and Limitations of the LISA Pathfinder Drag-Free Control System, Fichter et al

LPF

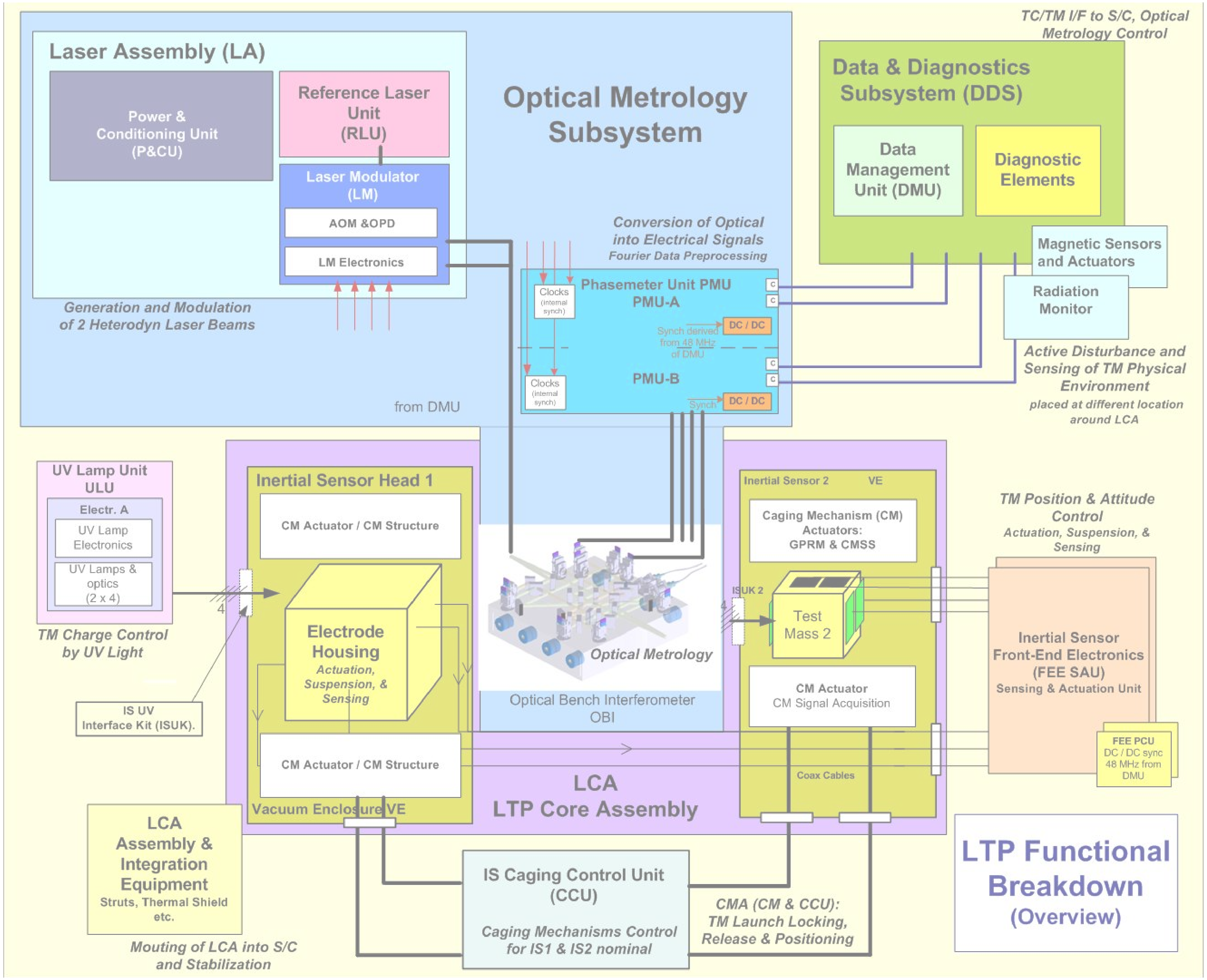


Components



Laser Assembly (LA)
Power & Conditioning Unit (P&CU)
Reference Laser Unit (RLU)
Laser Modulator (LM)
AOM &OPD
LM Electronics
Generation and Modulation of 2 Heterodyn Laser Beams
Optical Metrology Subsystem
Conversion of Optical into Electrical Signals
Fourier Data Preprocessing
Phasemeter Unit PMU
PMU-A
PMU-B
Clocks (internal synch)
Synch derived from 48 MHz of DMU
DC / DC
Synch
from DMU
TC/TM I/F to S/C, Optical Metrology Control
Data & Diagnostics Subsystem (DDS)
Data Management Unit (DMU)
Diagnostic Elements
Magnetic Sensors and Actuators
Radiation Monitor
Active Disturbance and Sensing of TM Physical Environment
placed at different location around LCA
UV Lamp Unit ULU
Electr. A
UV Lamp Electronics
UV Lamps & optics (2 x 4)
TM Charge Control by UV Light
IS UV Interface Kit (ISUK).
Inertial Sensor Head 1
CM Actuator / CM Structure
Electrode Housing
Actuation, Suspension, & Sensing
CM Actuator / CM Structure
Vacuum Enclosure VE
Optical Metrology
Optical Bench Interferometer OBI
Inertial Sensor 2
VE
Caging Mechanism (CM) Actuators: GPRM & CMSS
ISUK 2
Test Mass 2
CM Actuator
CM Signal Acquisition
Coax Cables
TM Position & Attitude Control
Actuation, Suspension, & Sensing
Inertial Sensor Front-End Electronics (FEE SAU)
Sensing & Actuation Unit
FEE PCU
DC / DC sync 48 MHz from DMU
LCA
LTP Core Assembly
LCA Assembly & Integration Equipment
Struts, Thermal Shield etc.
Mouting of LCA into S/C and Stabilization
IS Caging Control Unit (CCU)
Caging Mechanisms Control for IS1 & IS2 nominal
CMA (CM & CCU): TM Launch Locking, Release & Positioning
LTP Functional Breakdown (Overview)

Components



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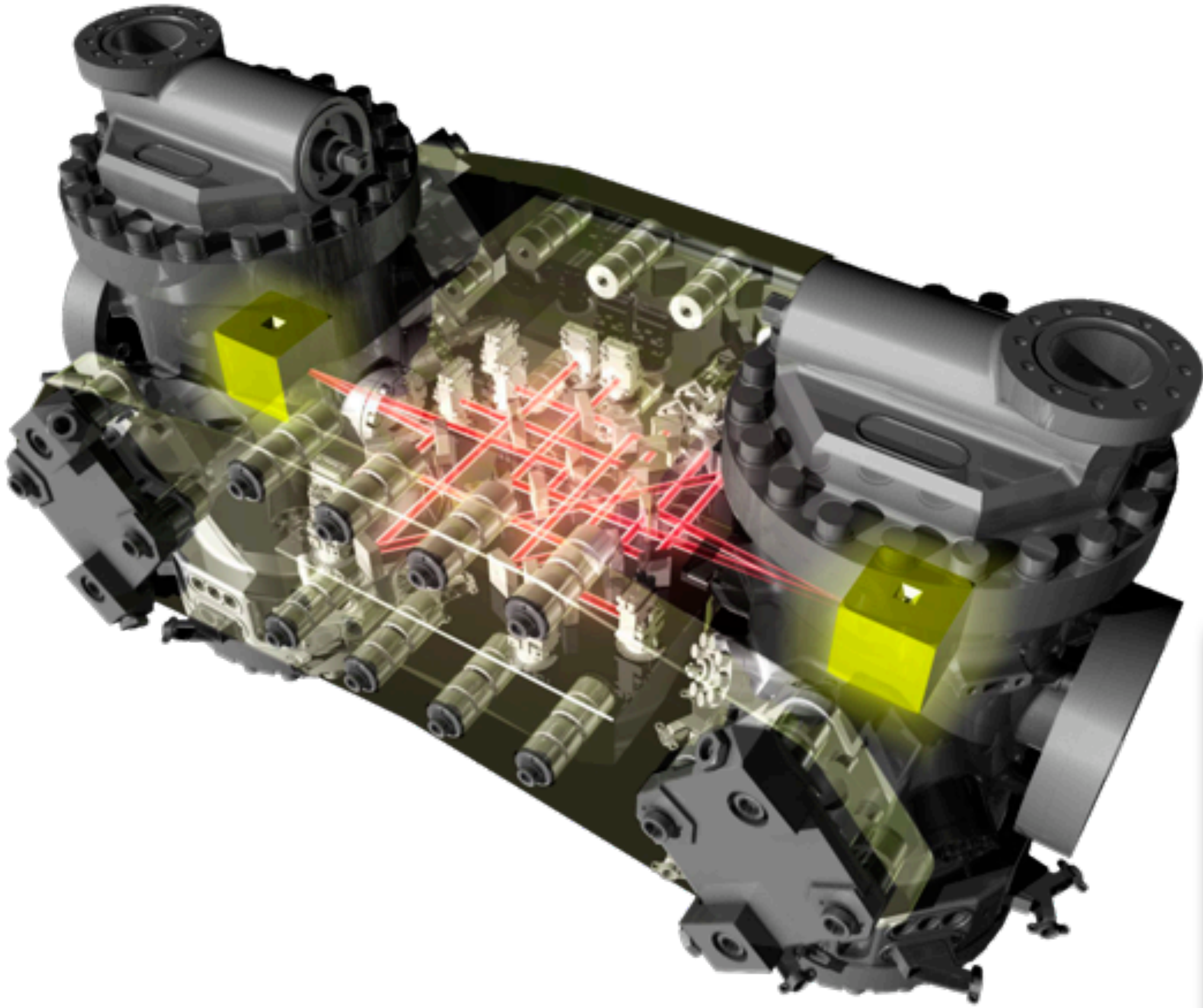
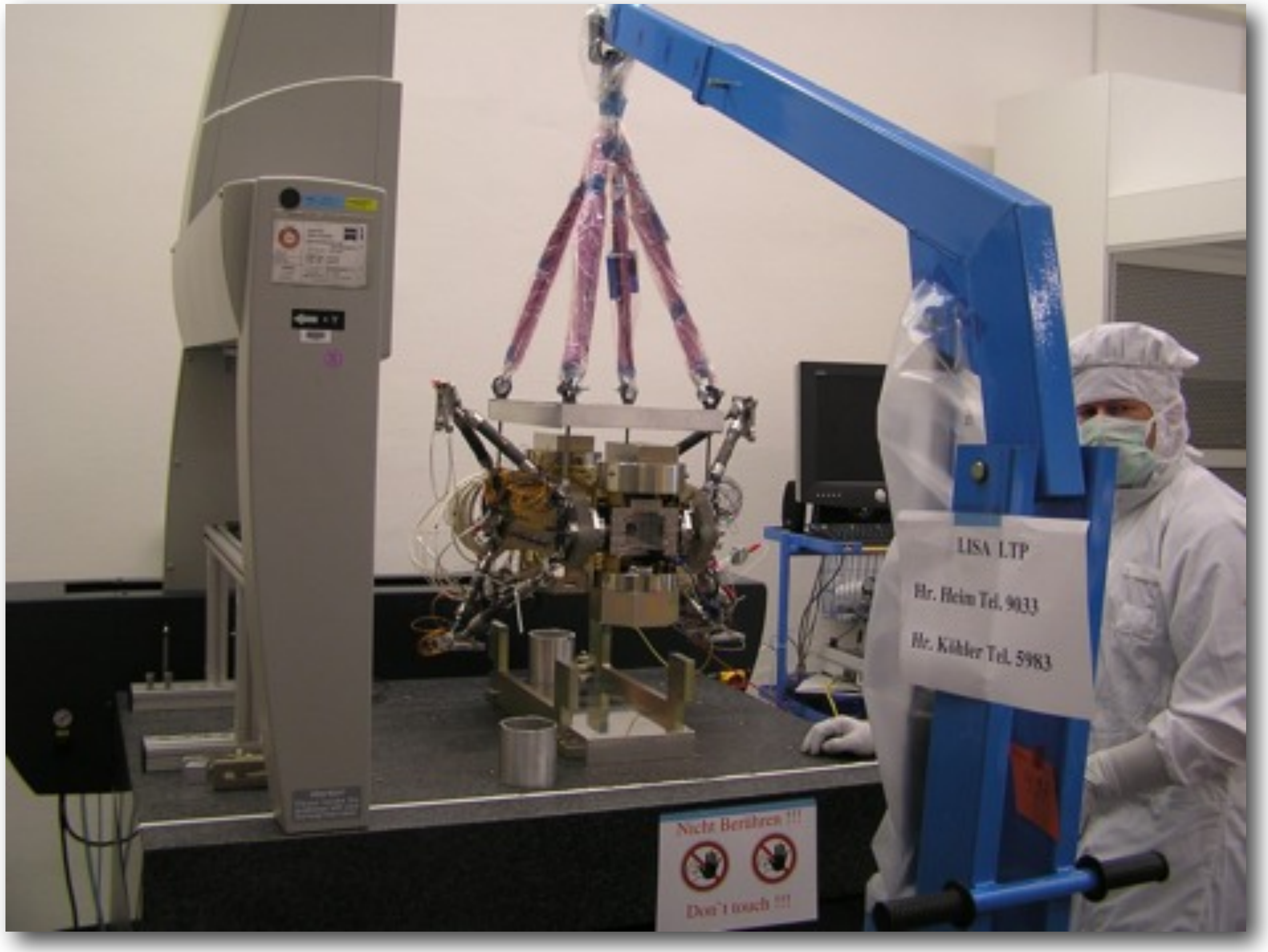
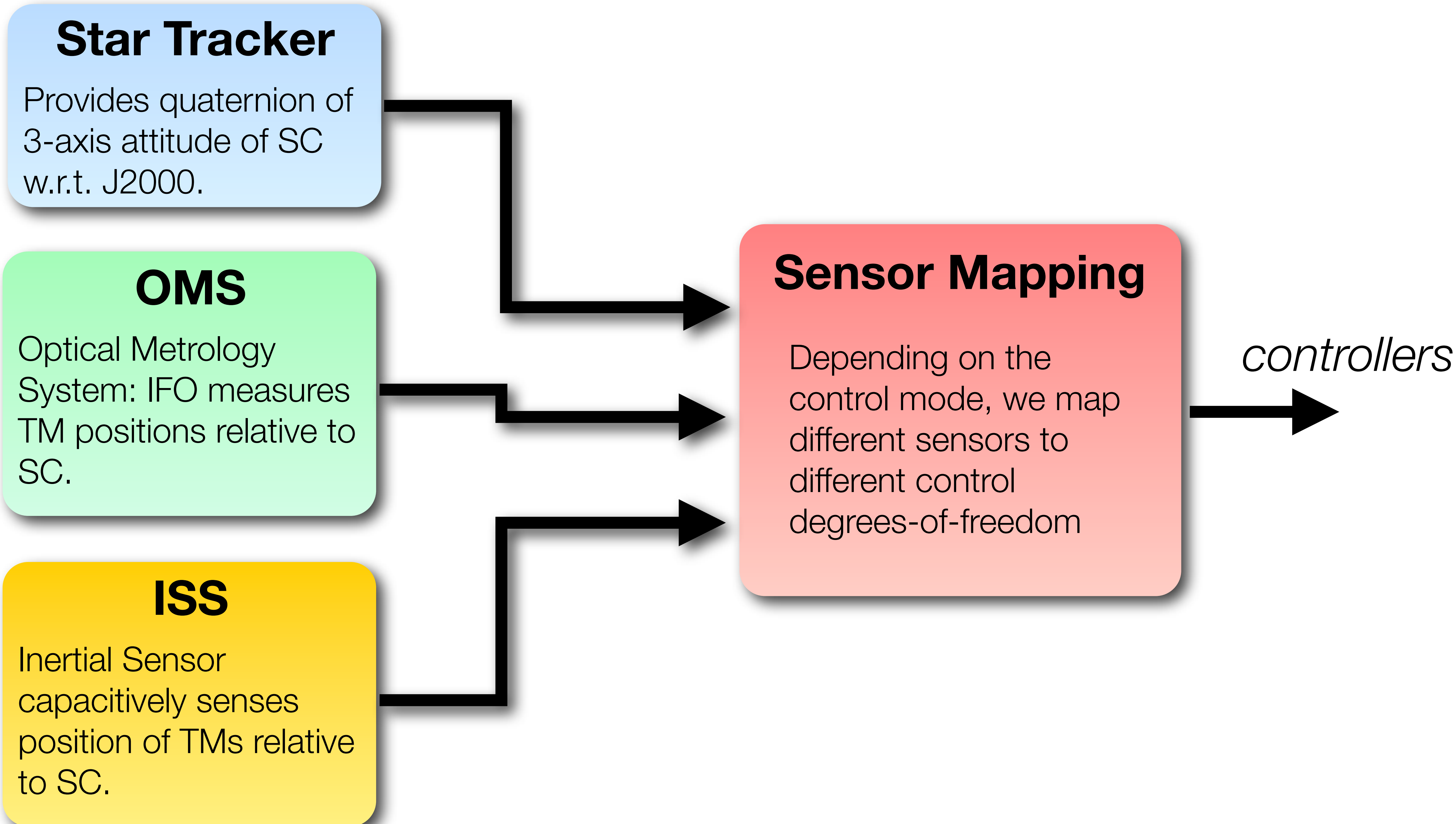


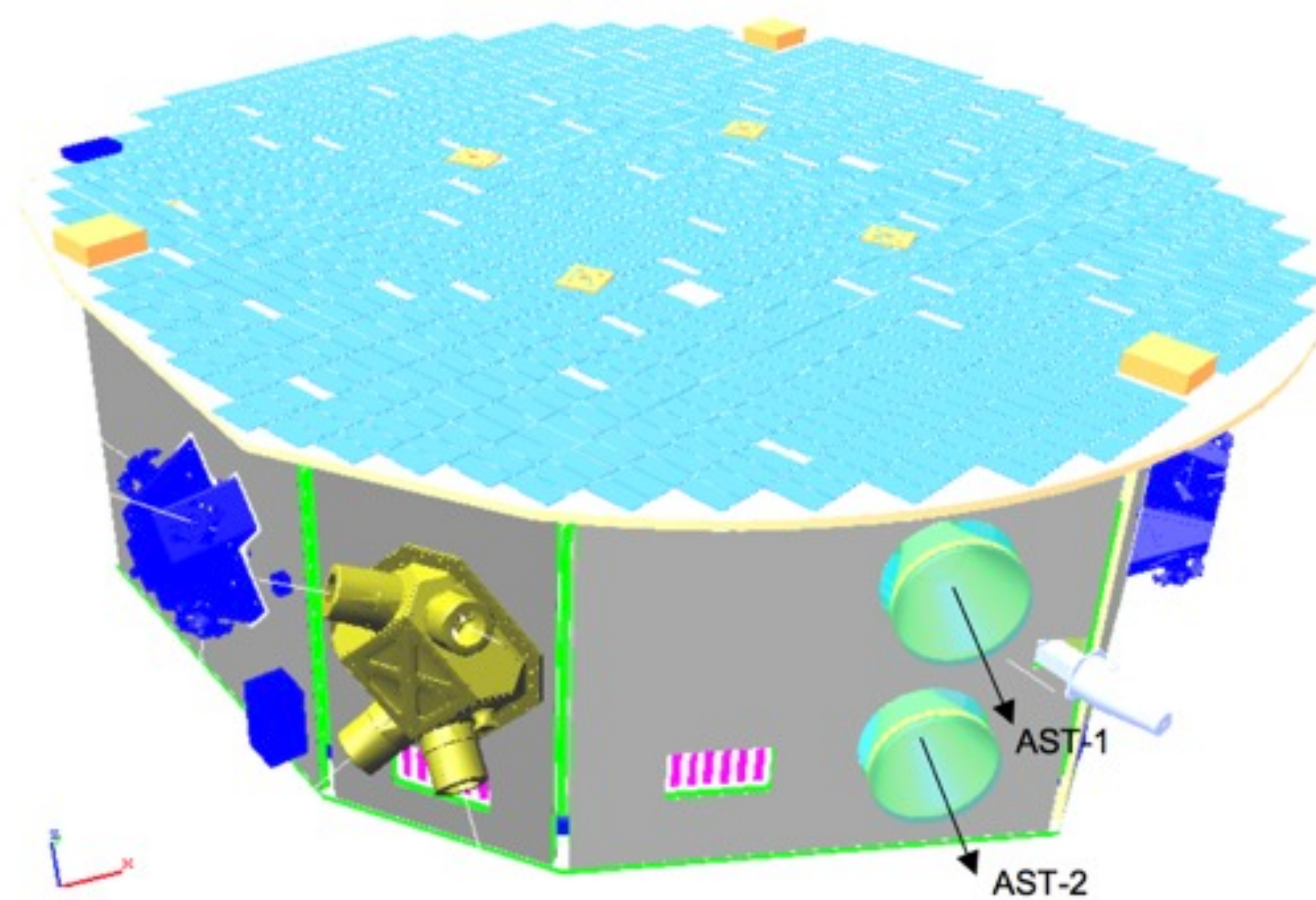

LISA LTP
Hr. Heim Tel. 9033
Hr. Köhler Tel. 5983
Nicht Berühren !!!
Don't touch !!!

Sensing the motion



Autonomous Star Trackers

- Sense the attitude of the SC w.r.t. to the 'fixed' stars
- Accuracy of about 100 arcsecs / rtHz at 1mHz
- Produces measurements at 2Hz



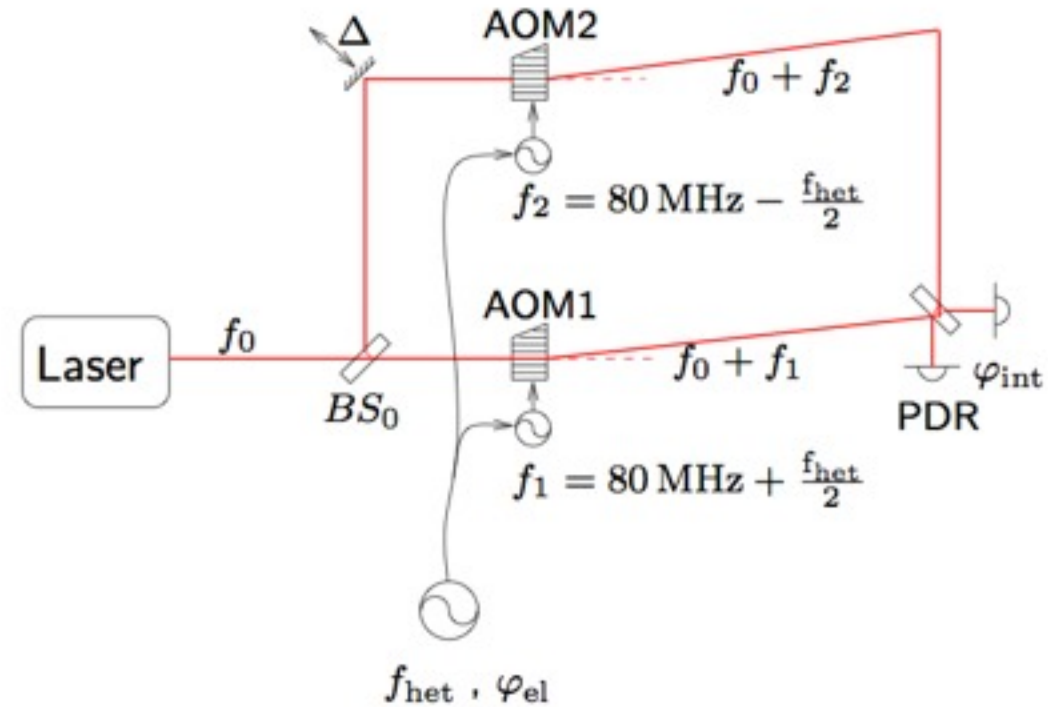
OMS

$f_{\mathrm{het}} \approx 1.6\,\mathrm{kHz}$

$$x \approx 9\,\mathrm{pm}/\sqrt{\mathrm{Hz}} \text{ at } 3\,\mathrm{mHz}$$

$$\phi \approx 10\,\mathrm{nrad}/\sqrt{\mathrm{Hz}} \text{ at } 3\,\mathrm{mHz}$$

- We use 4 Mach-Zehnder IFOs



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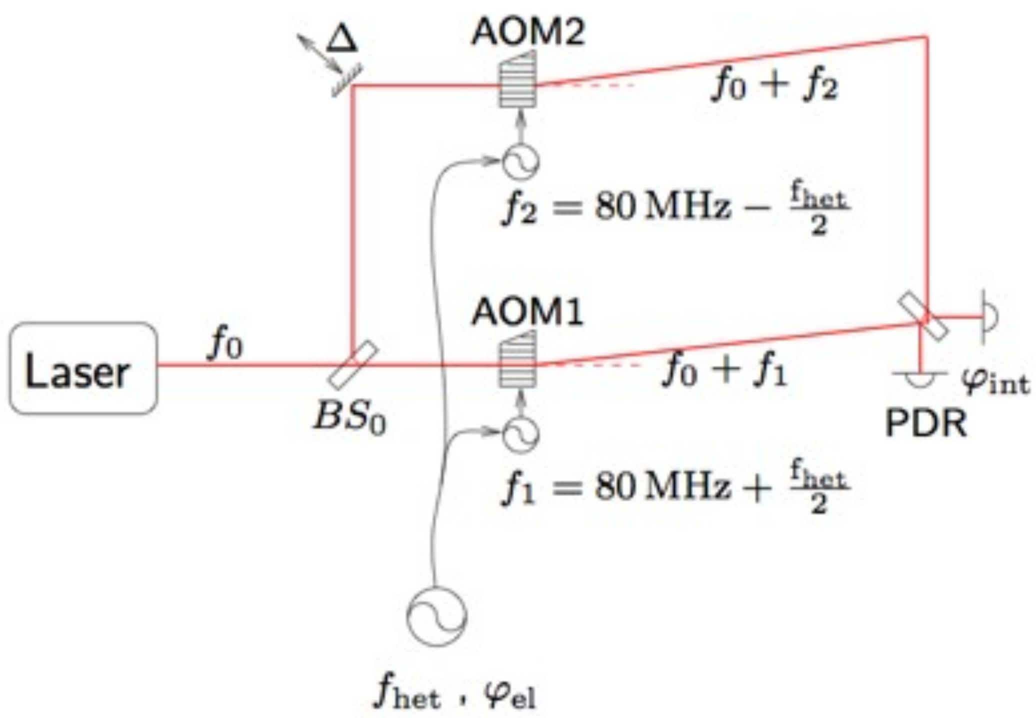
  - also measures two angles (phi, eta) with DWS
    - roll around beam is not measured



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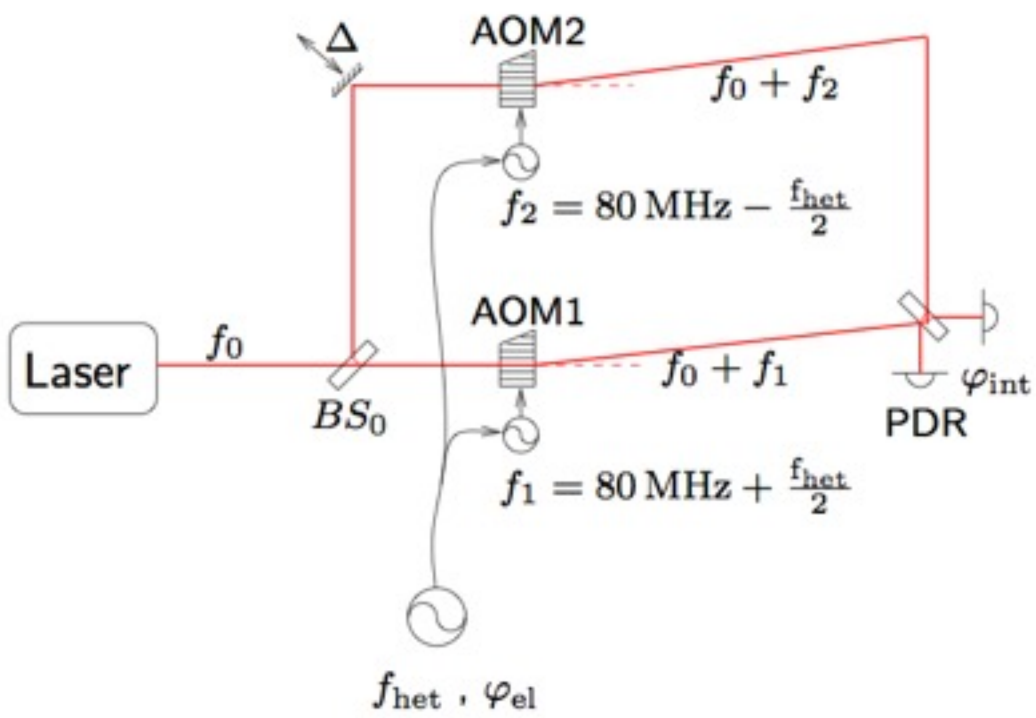

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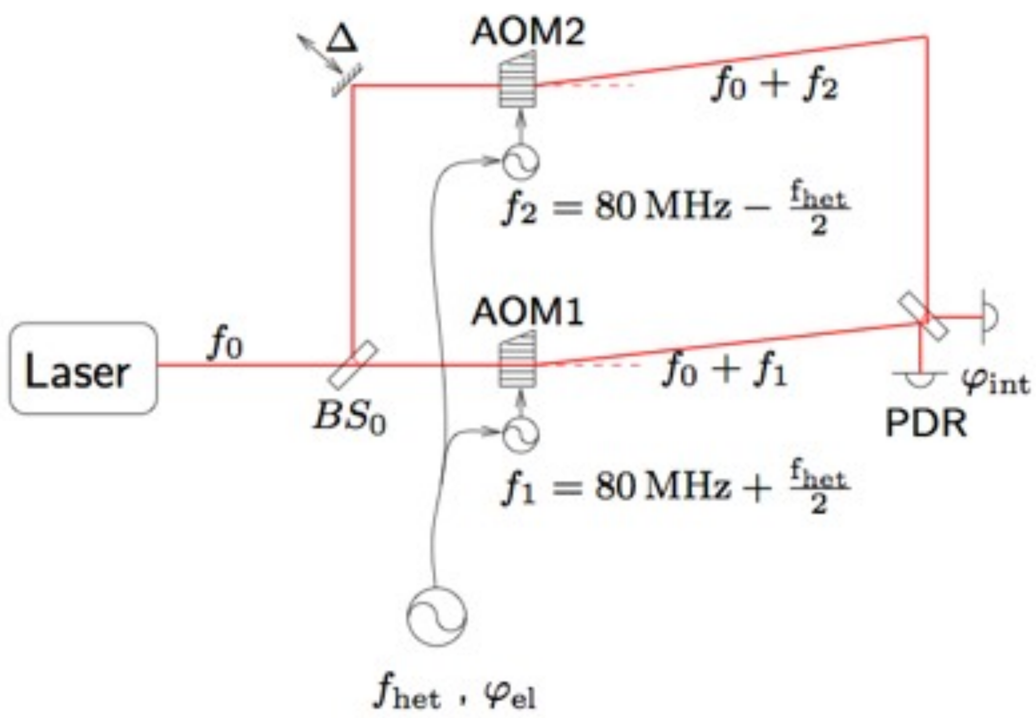

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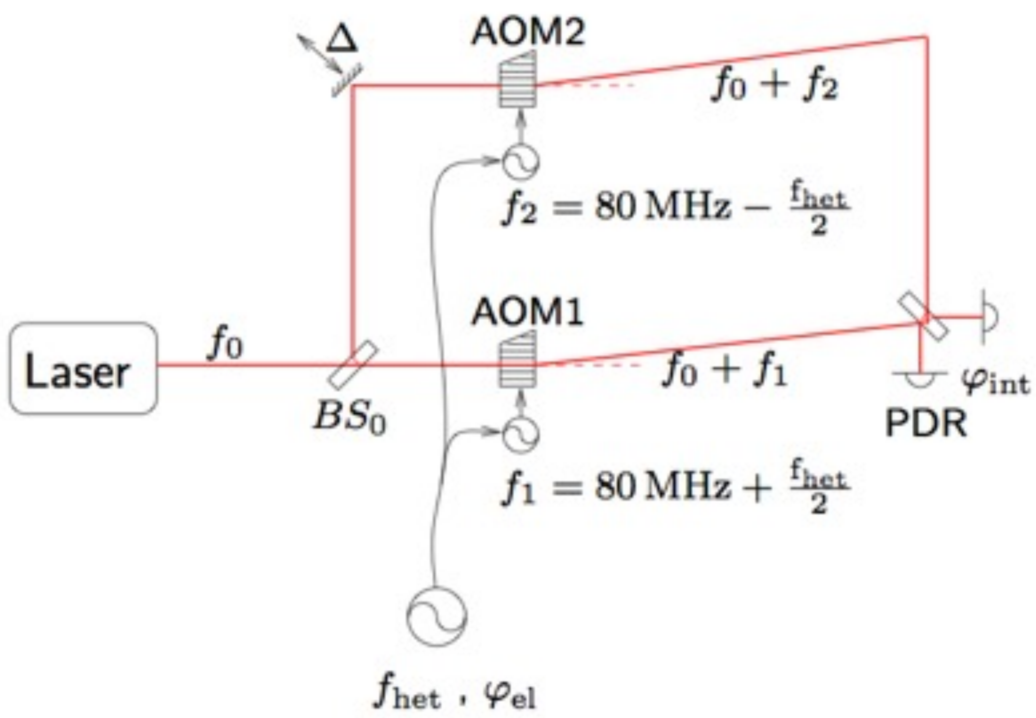
- Fixed IFO with unequal arms to measure frequency noise
- Fixed IFO with equal arms as a reference measurement
  - measures the IFO noise



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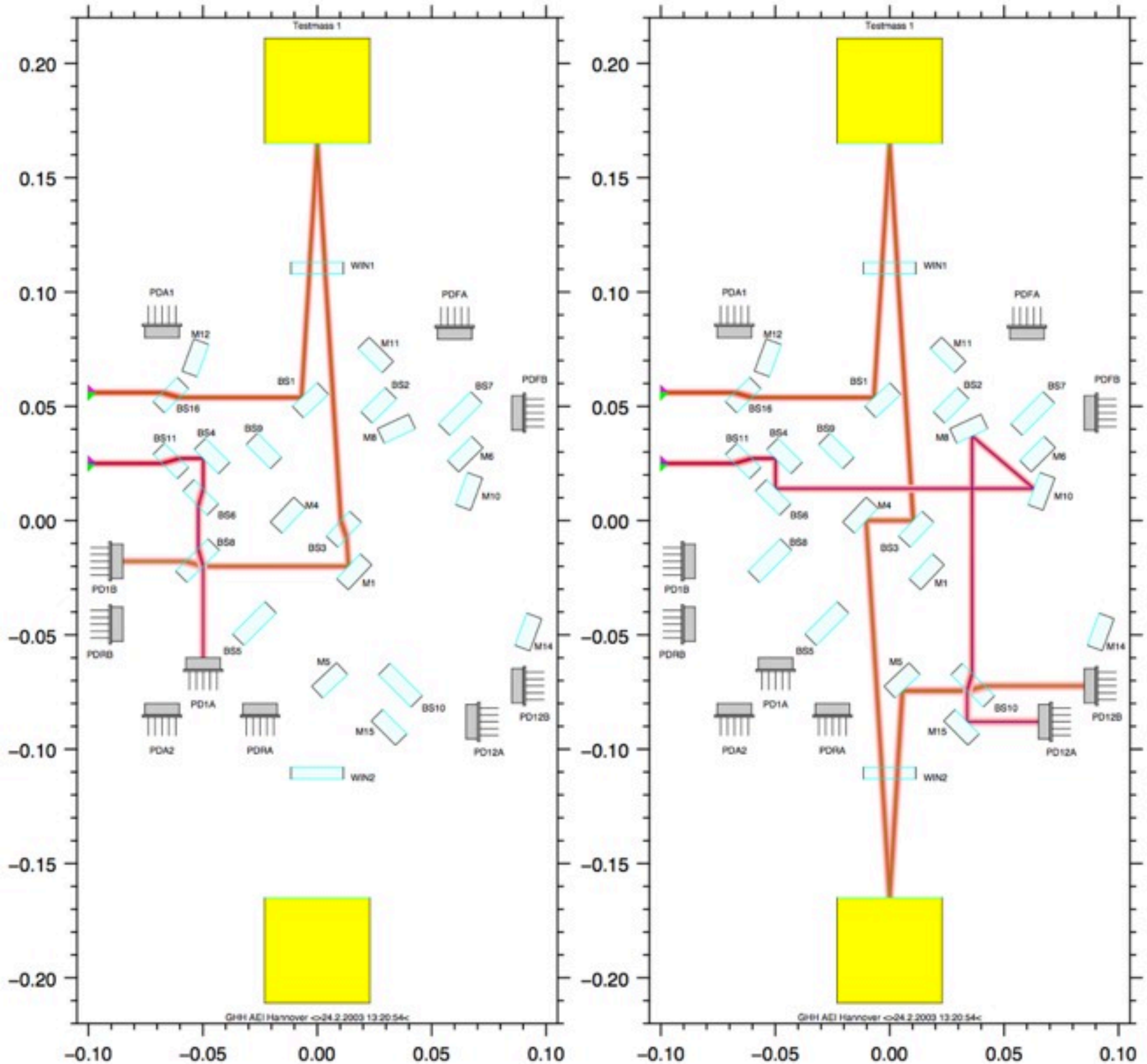
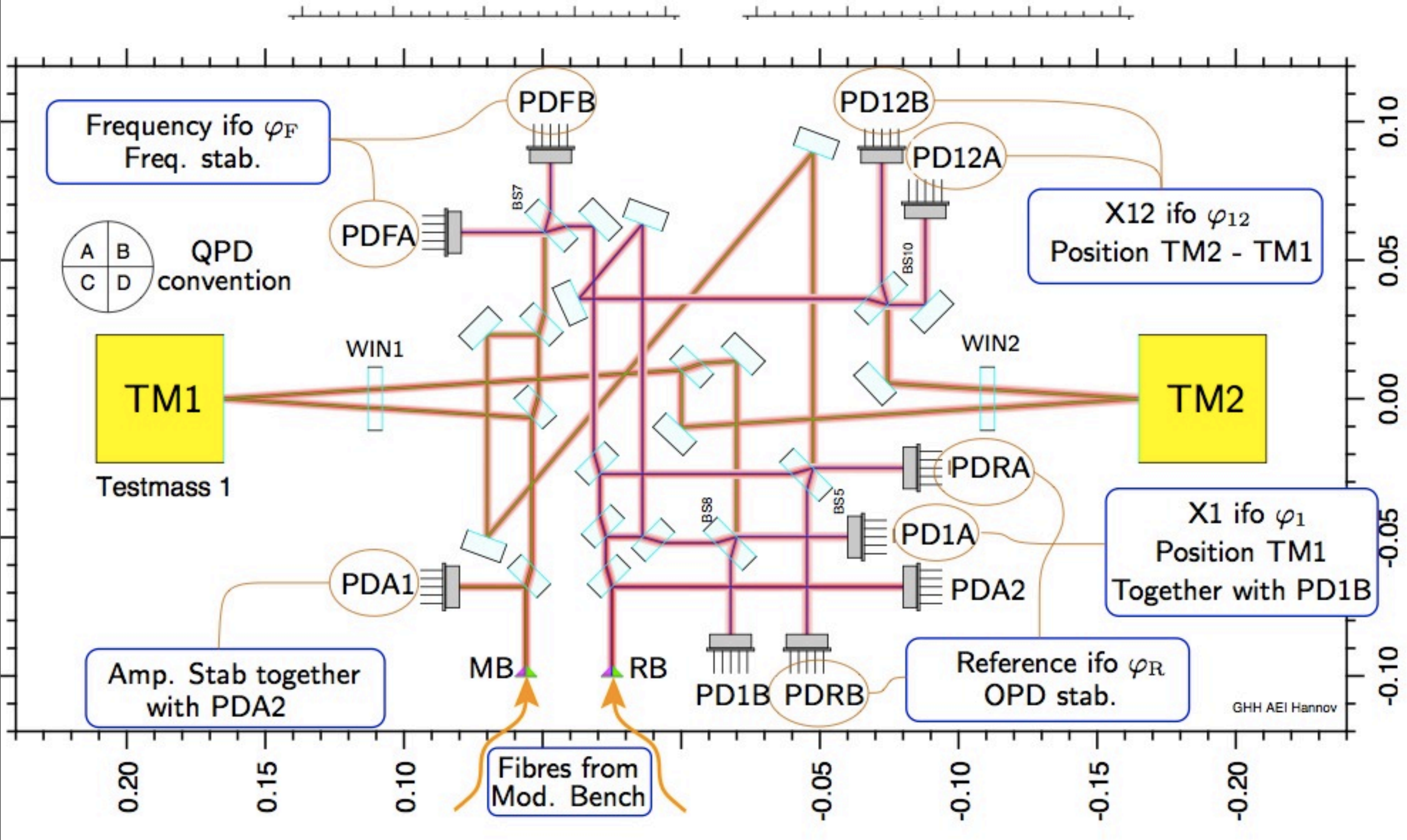
X1 and X12



Testmass 1
WIN1
WIN2
PDA1
PDFA
PDFB
M12
M11
BS1
BS2
BS7
BS16
BS11
BS4
BS9
M8
M6
M10
M4
BS6
BS8
BS3
M1
PD1B
PDRB
M14
BS5
M5
PD1A
BS10
PD12B
PDA2
PDRA
M15
PD12A

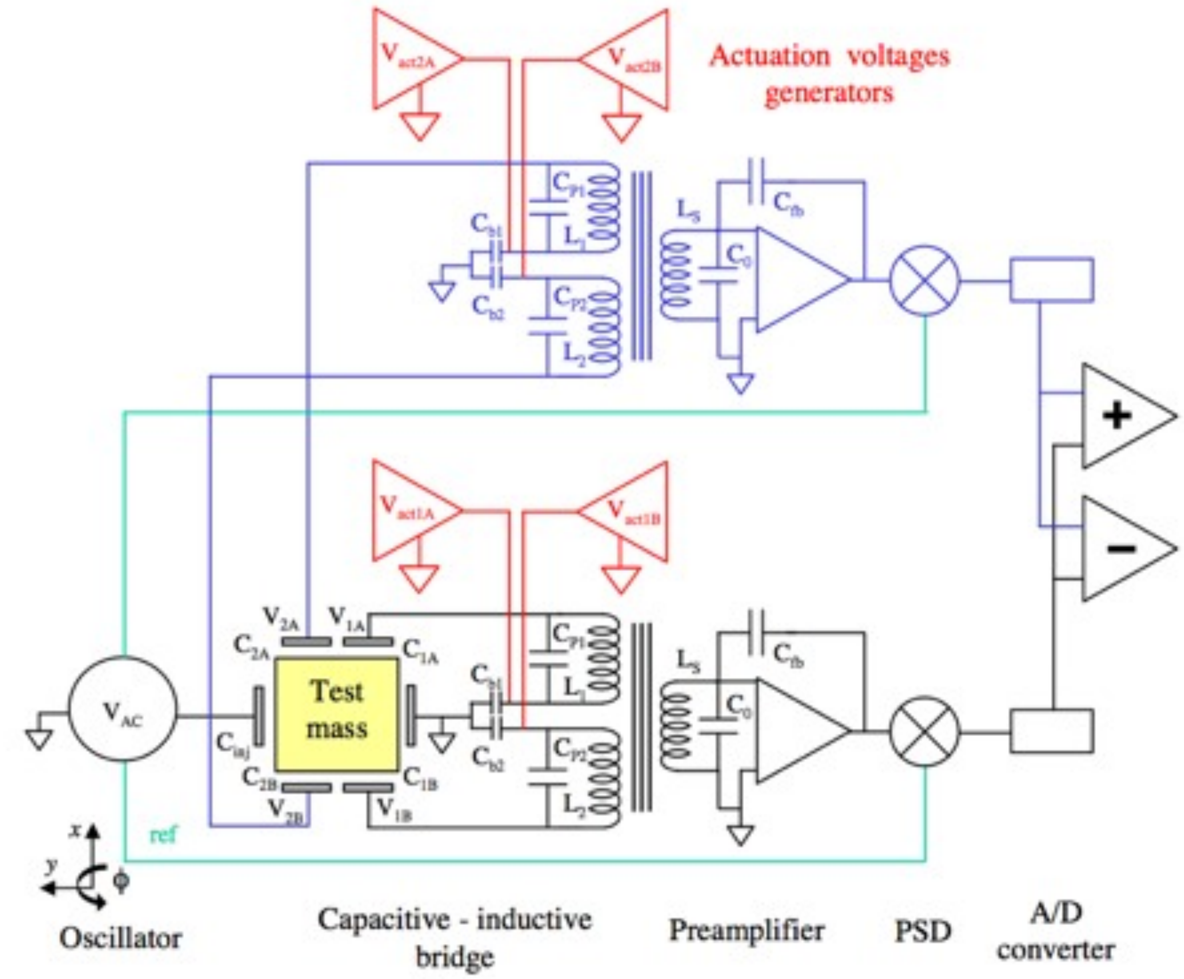
X1 and X12

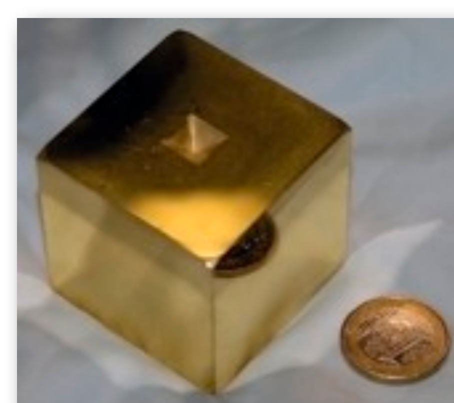


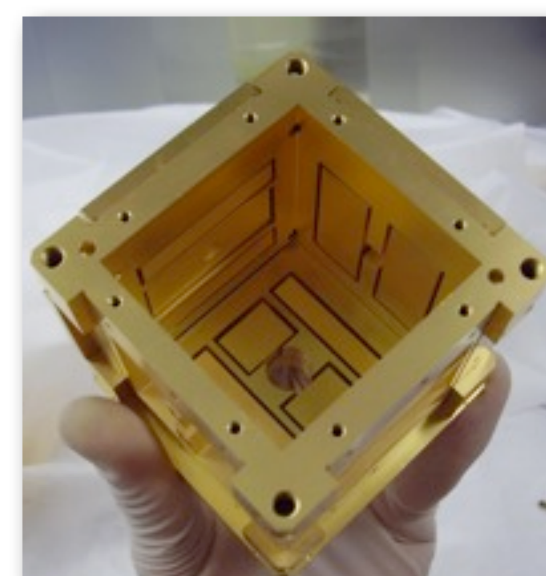
Frequency ifo φ_F
Freq. stab.
PDFB
PD12B
PD12A
X12 ifo φ_{12}
Position TM2 - TM1
PDFA
BS7
BS10
QPD convention
A
B
C
D
TM1
Testmass 1
WIN1
WIN2
TM2
PDRA
BS8
BS5
PD1A
X1 ifo φ_1
Position TM1
Together with PD1B
PDA1
PDA2
Amp. Stab together with PDA2
MB
RB
PD1B
PDRB
Reference ifo φ_R
OPD stab.
GHH AEI Hannov
Fibres from Mod. Bench
0.10
0.05
0.00
-0.05
-0.10
0.20
0.15
0.10
-0.05
-0.10
-0.15
-0.20

Inertial Sensors

- Each test-mass is surrounded by a housing containing multiple electrodes
- With these electrodes we can sense the position of the TM w.r.t. the housing
  - ~1nm/rtHz @ 1mHz
- We can also apply forces between the TM and housing

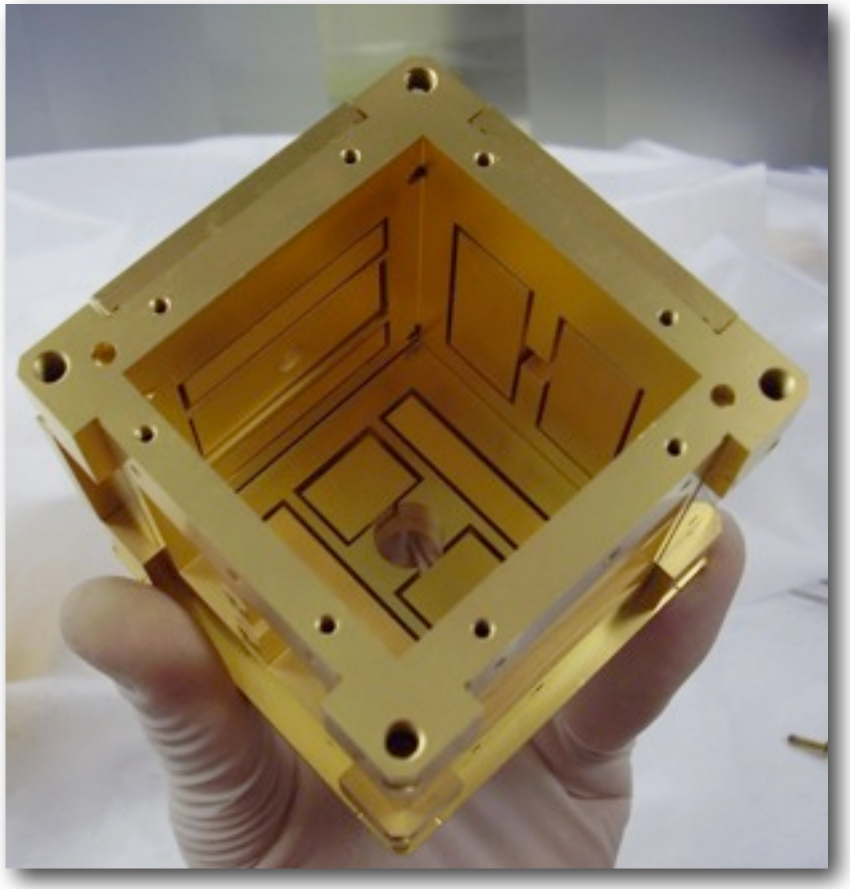






Actuation

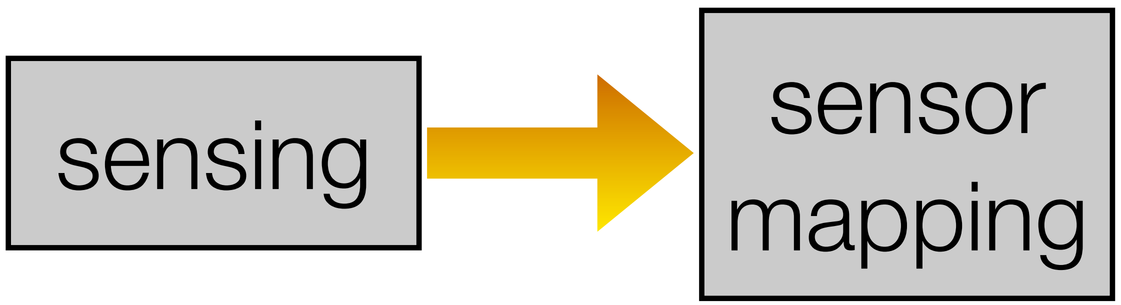
- We have two types of actuator:
  - the micro-propulsion system on the SC
    - 6 degrees-of-freedom
    - up to 100 uN thrust with uN accuracy
  - electrostatic actuation on each TM
    - 6 degrees-of-freedom per TM
    - >uN force with fN accuracy



Control architecture

sensing

Control architecture



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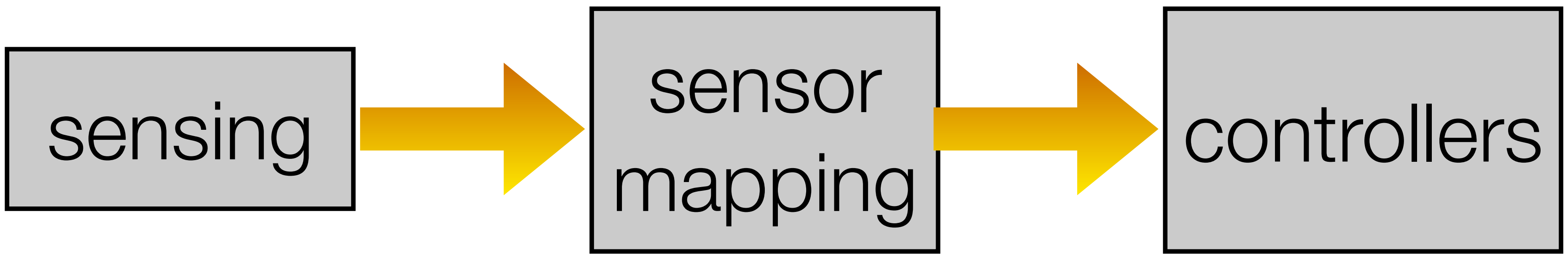

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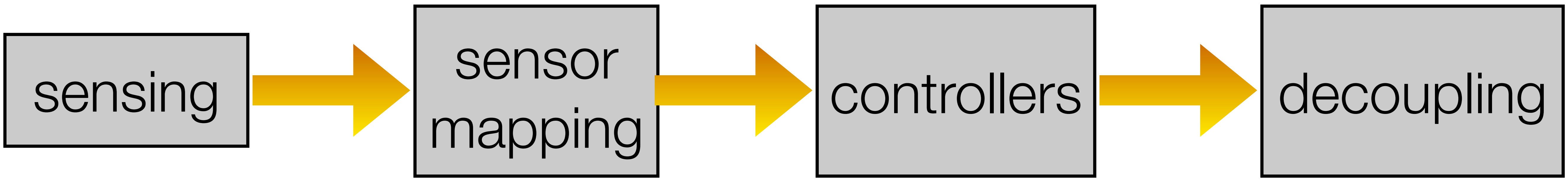

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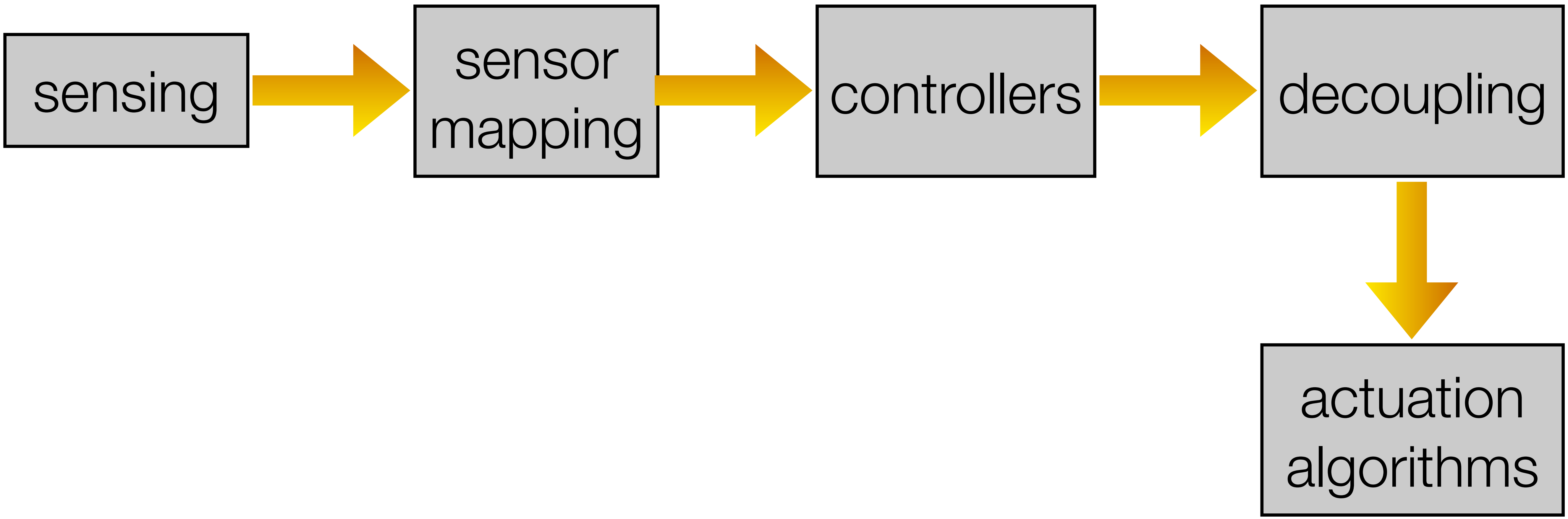

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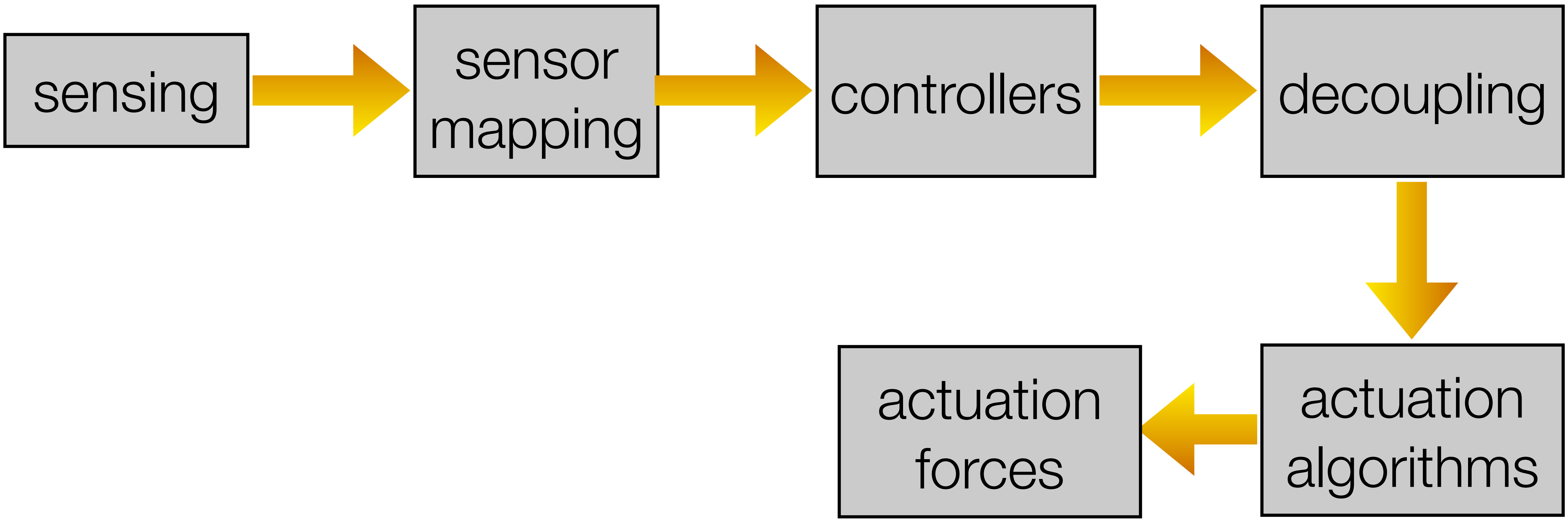

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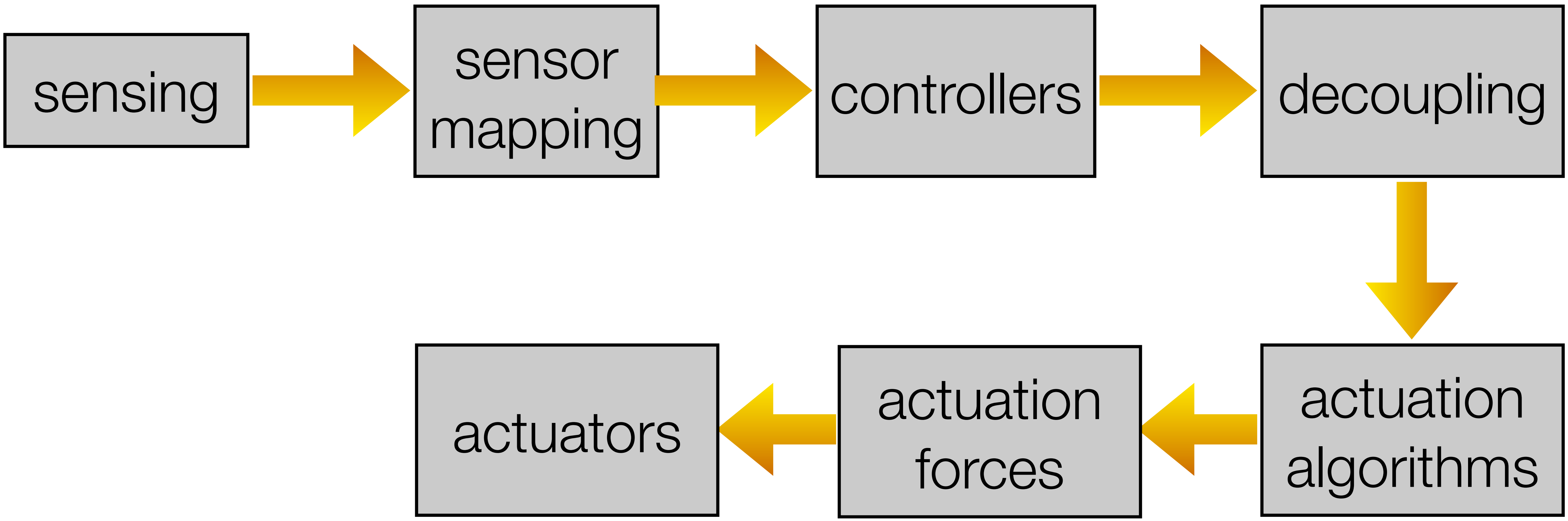

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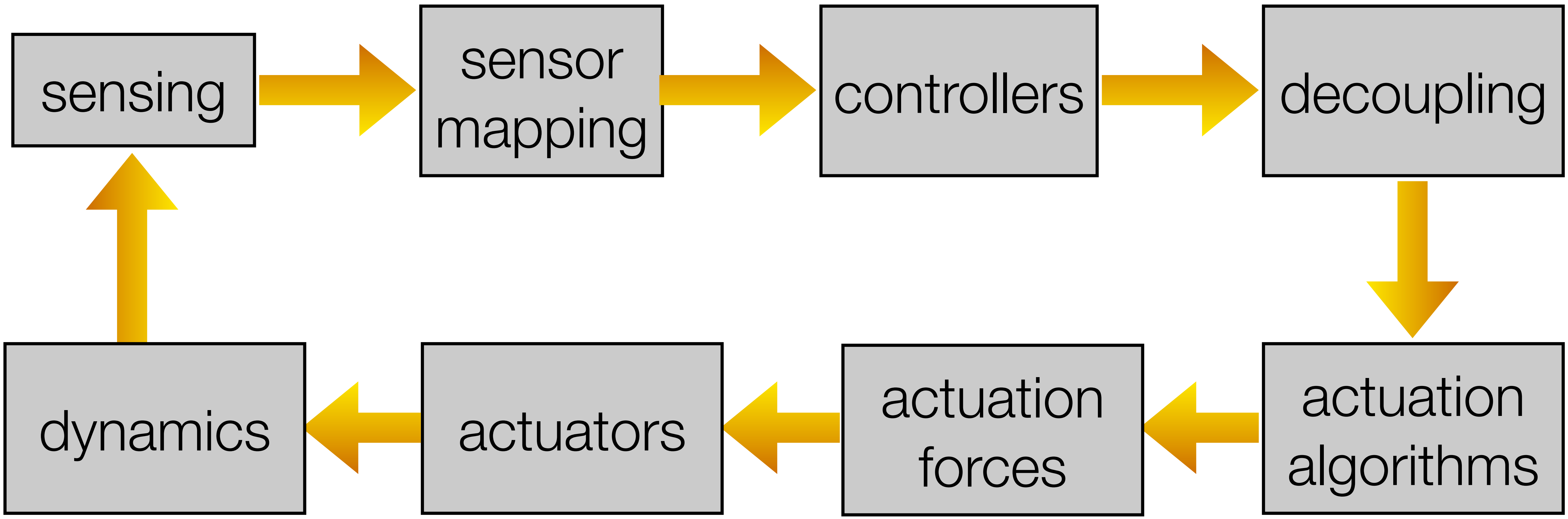
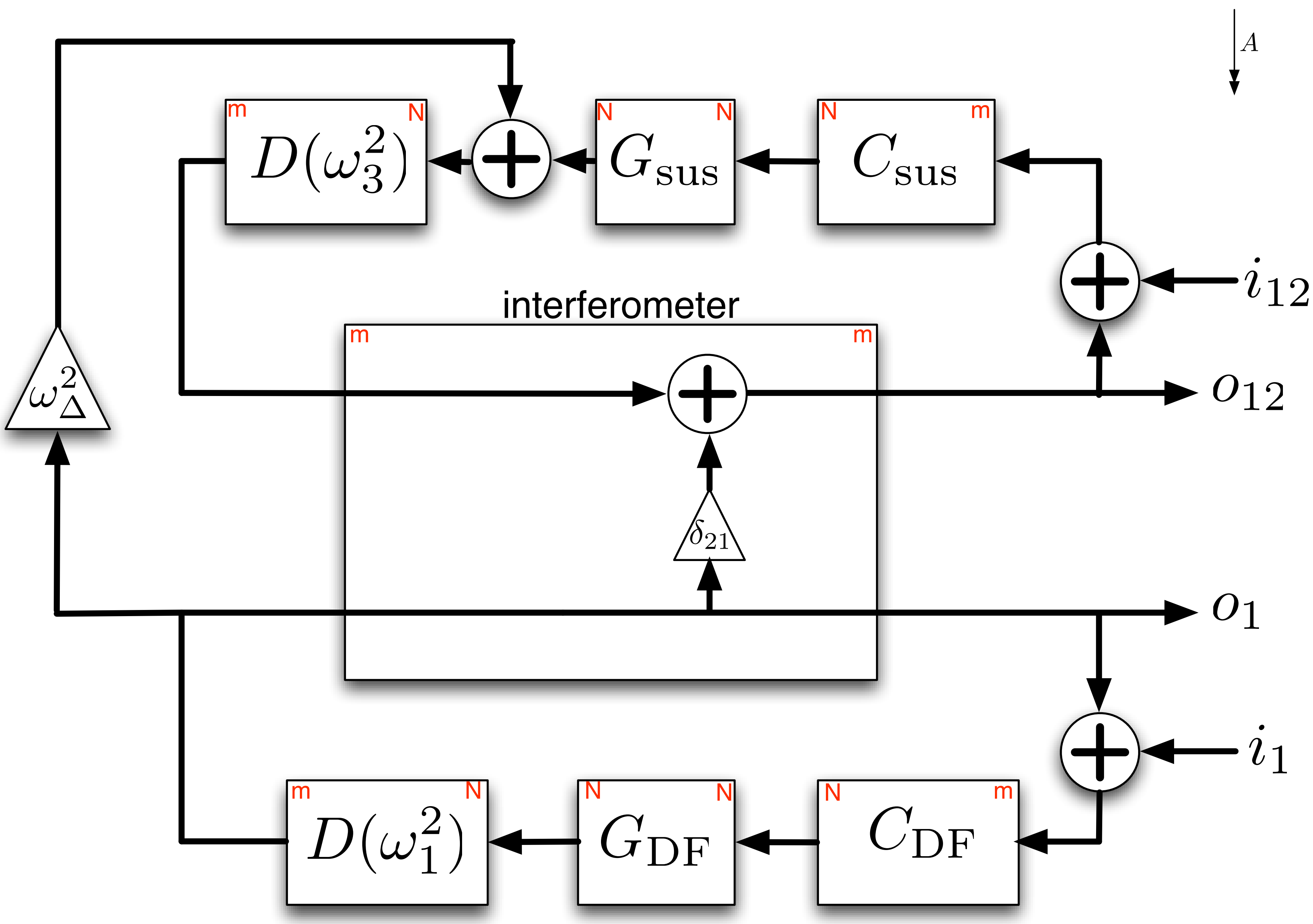
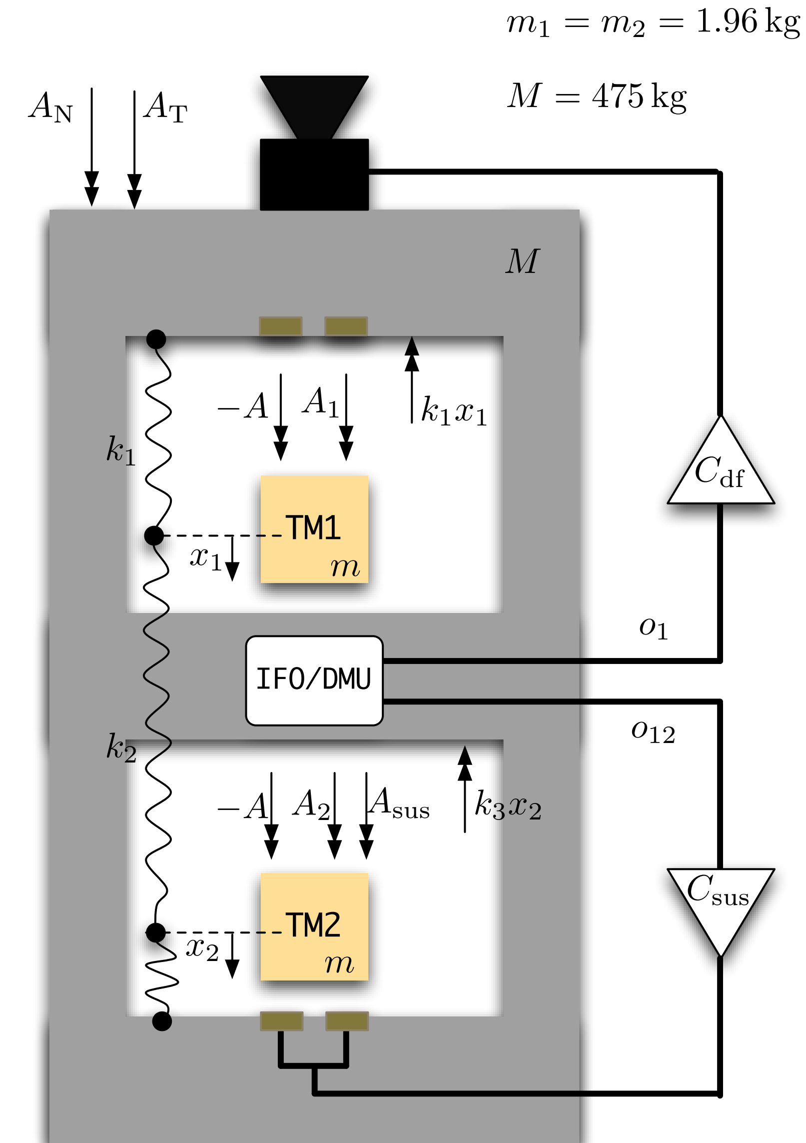


x-axis loop diagrams

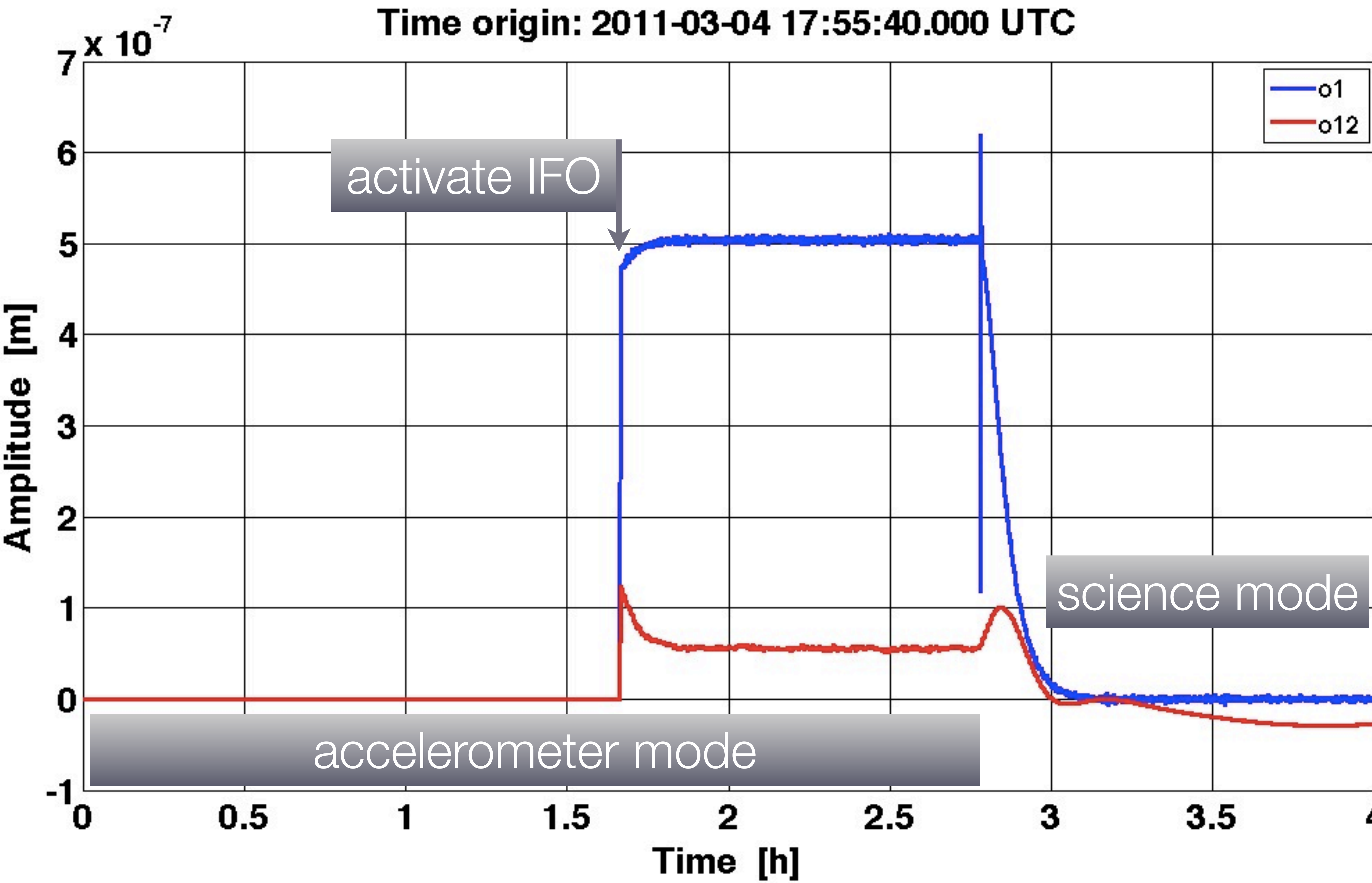




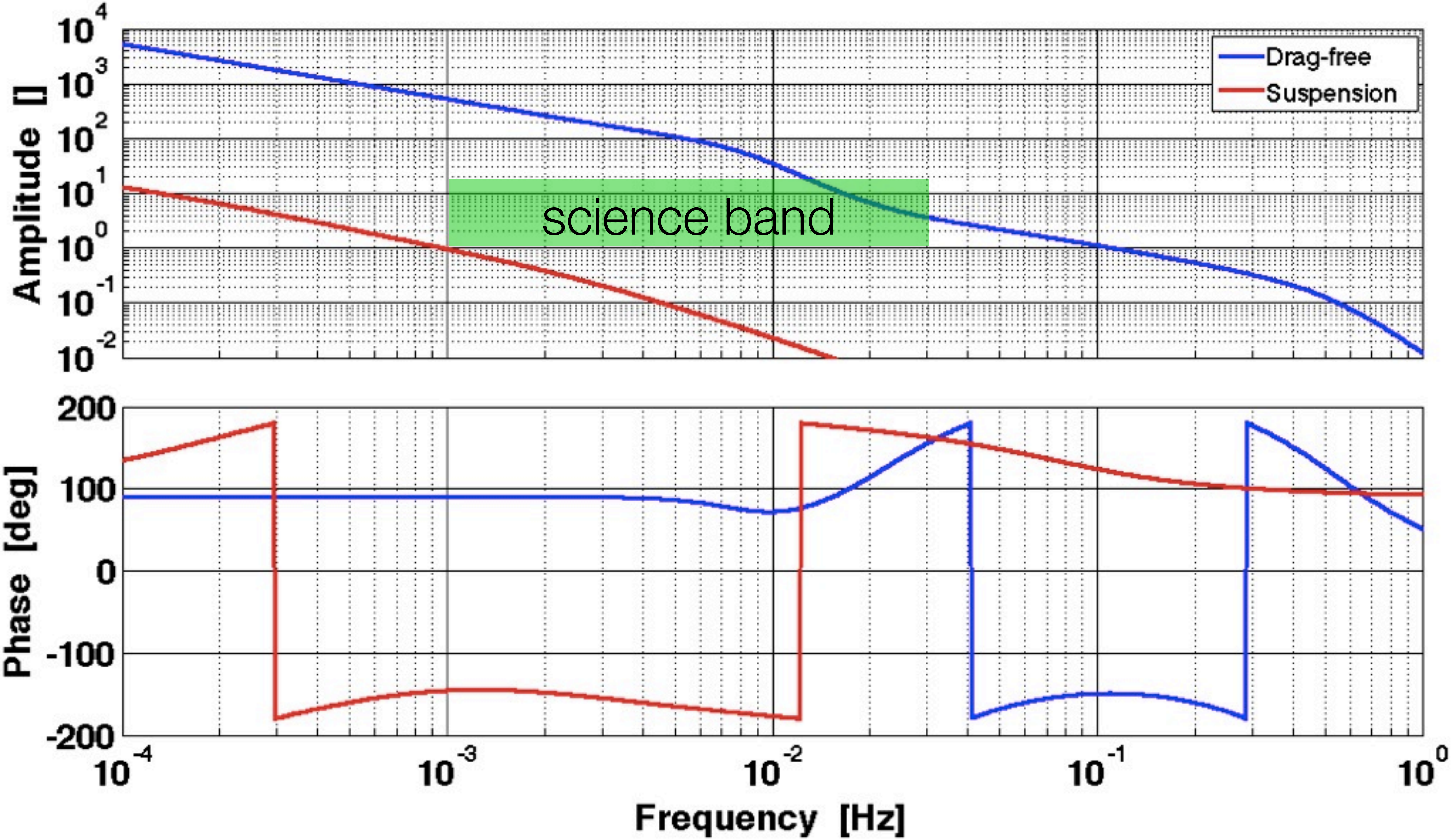
Getting to science mode

1. Release TMs
2. Grab test-masses in accelerometer mode
   1. both TMs are ‘locked’ to the SC via capacitive sensing and actuation
3. Activate IFOs
4. Switch SC-TM1 position sensing to IFO X1 and change controller
5. Switch TM1-TM2 position sensing to IFO X12 and change controller

Entering science mode



Open-loop gains



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- Actuation causes noise

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- Do an experiment where the TM2 x-actuation is off
  - at least briefly

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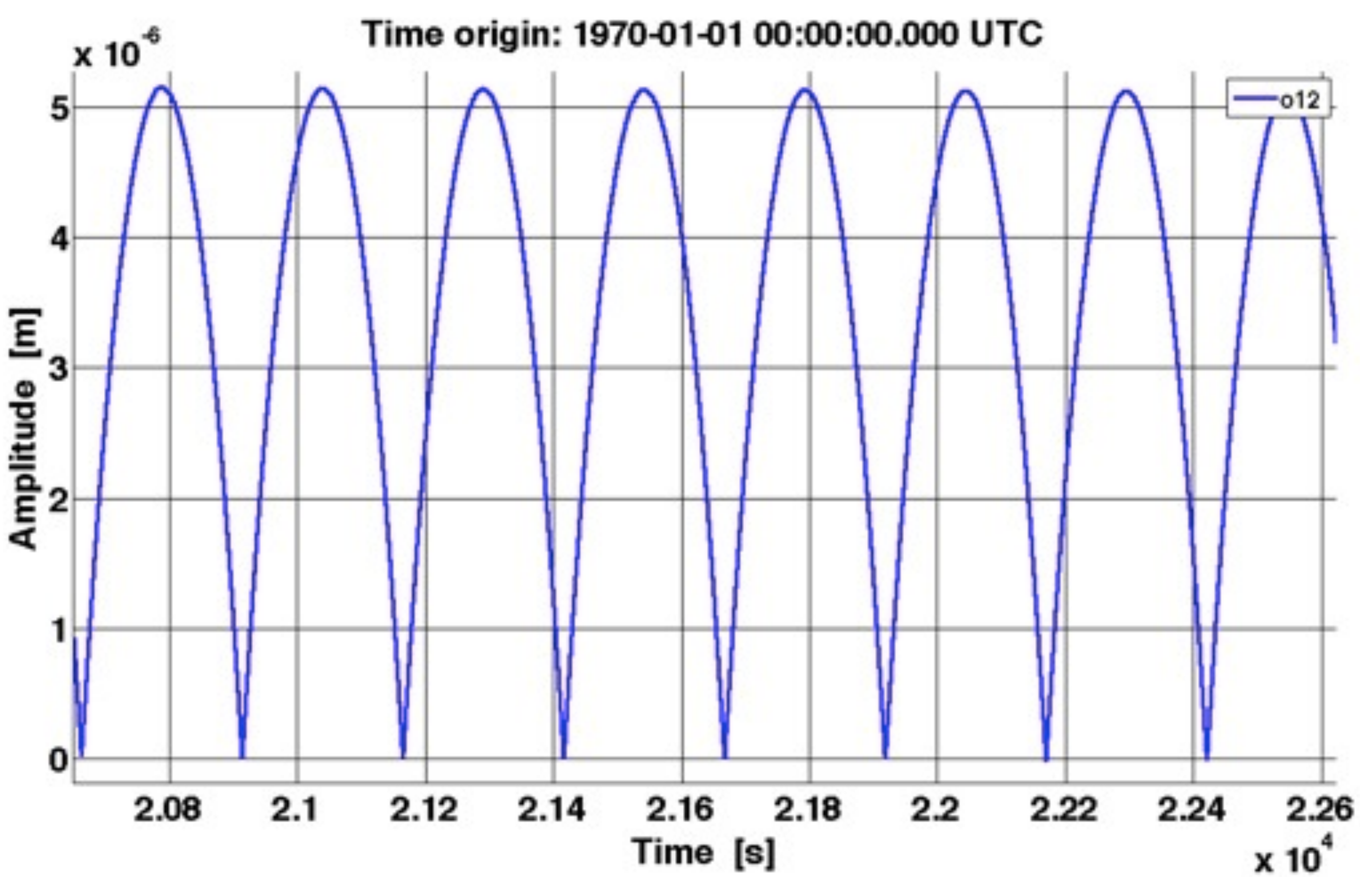
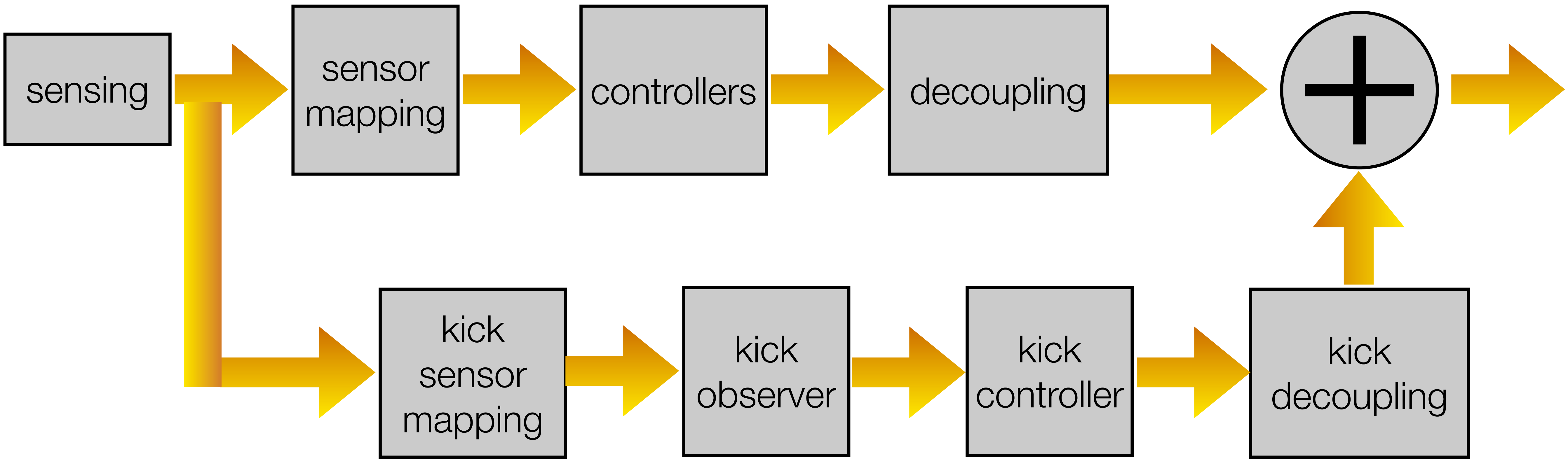
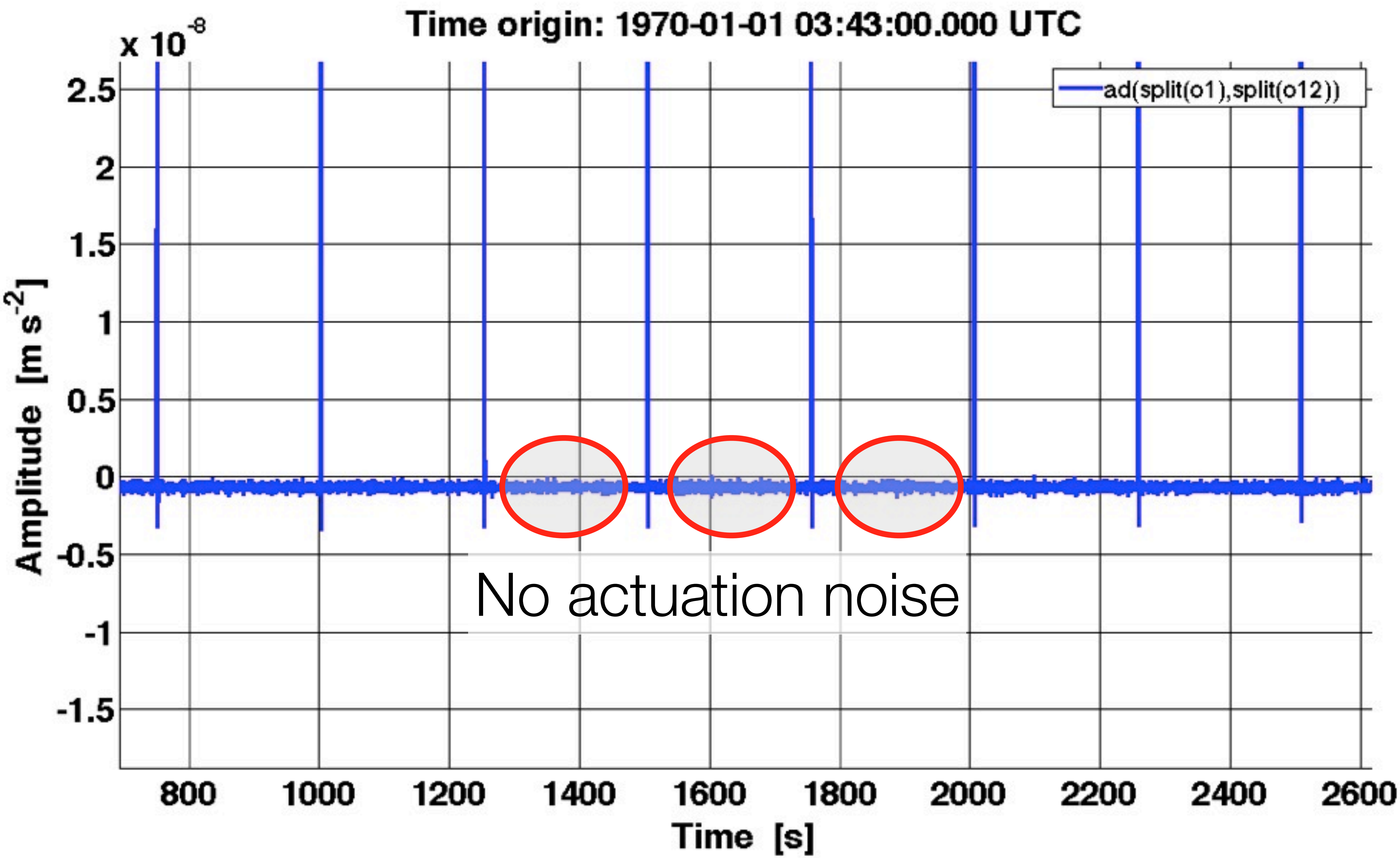


New control-mode



Acceleration



The End