UNIVERSITÀ DEGLI STUDI DI TRENTO

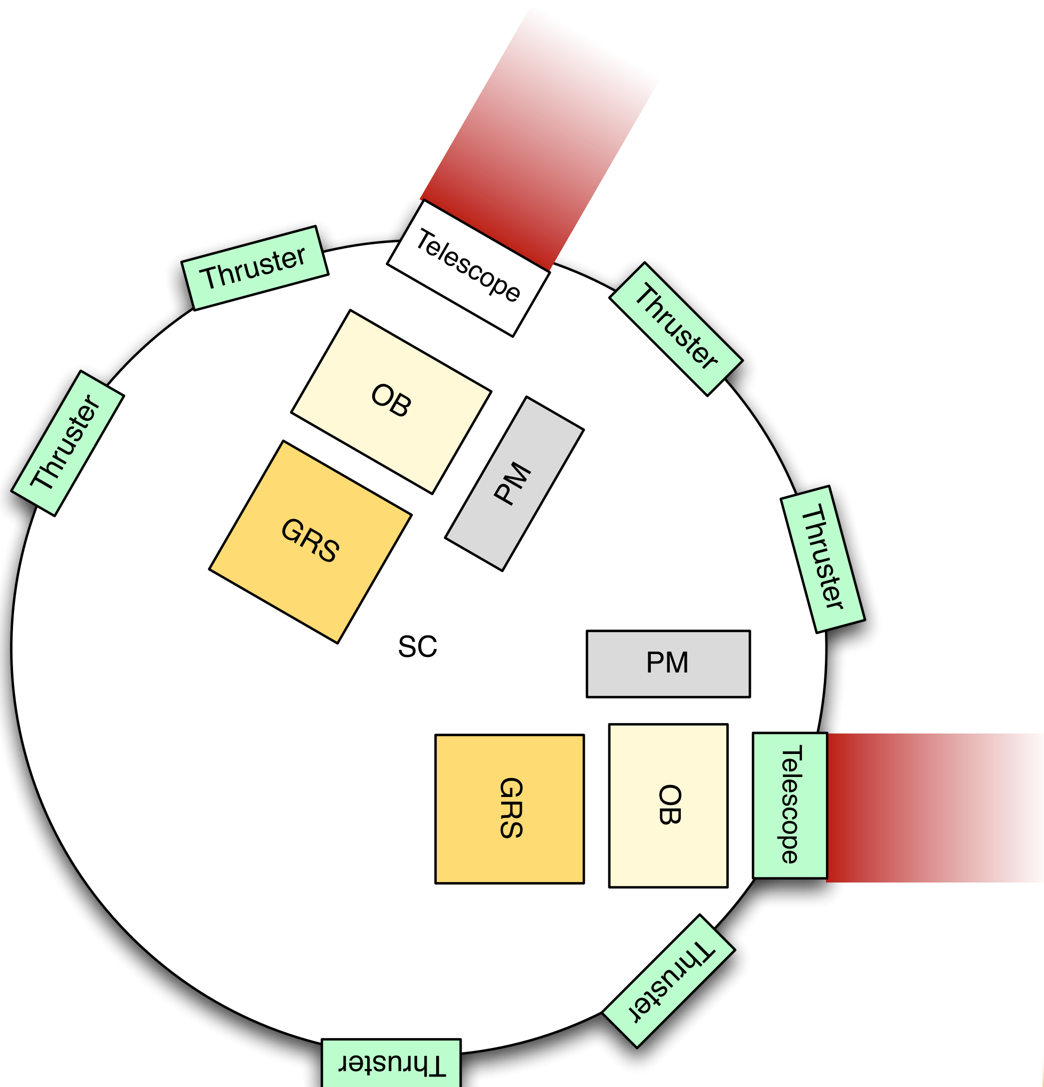
esa SCIENCE

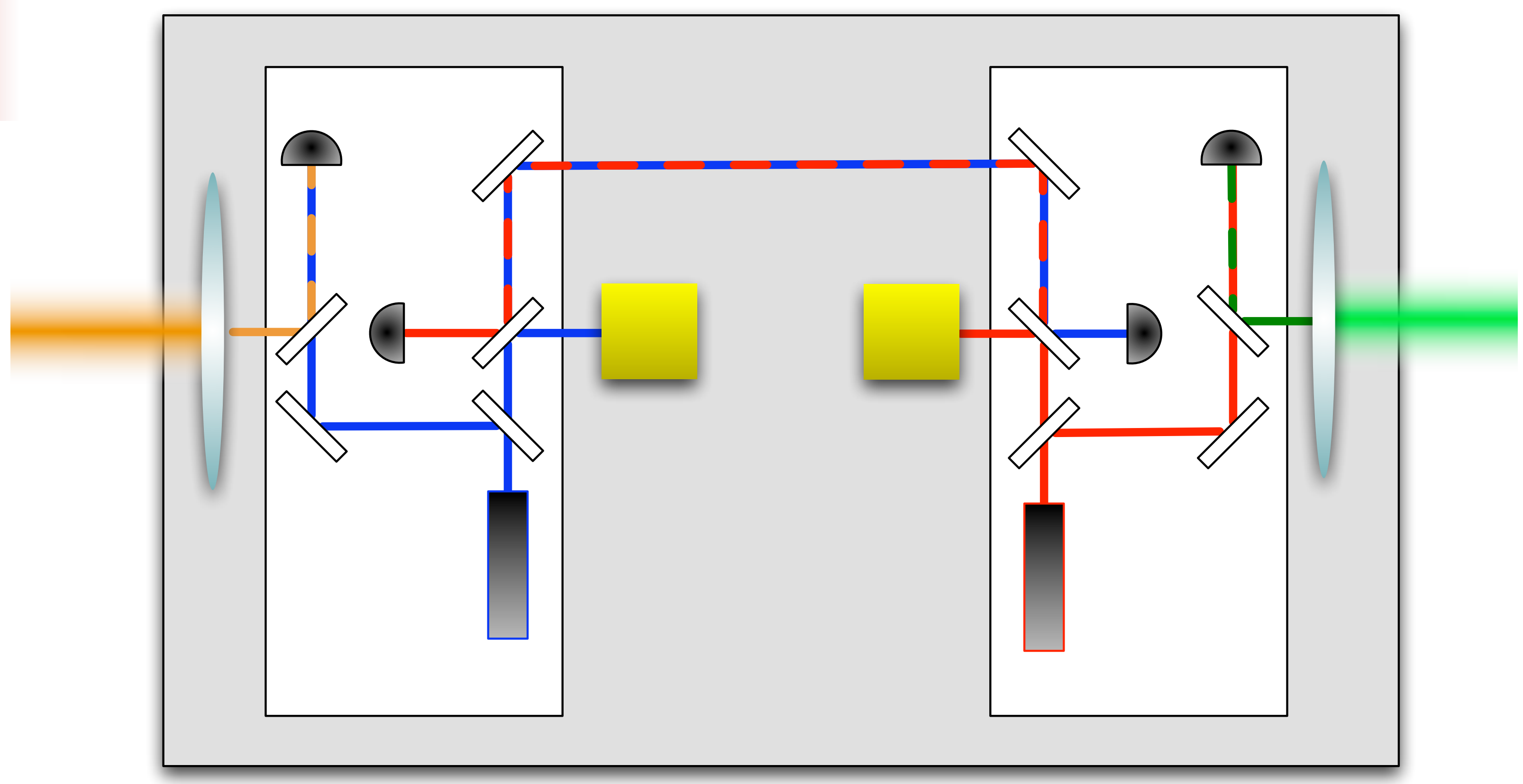
LISA Pathfinder

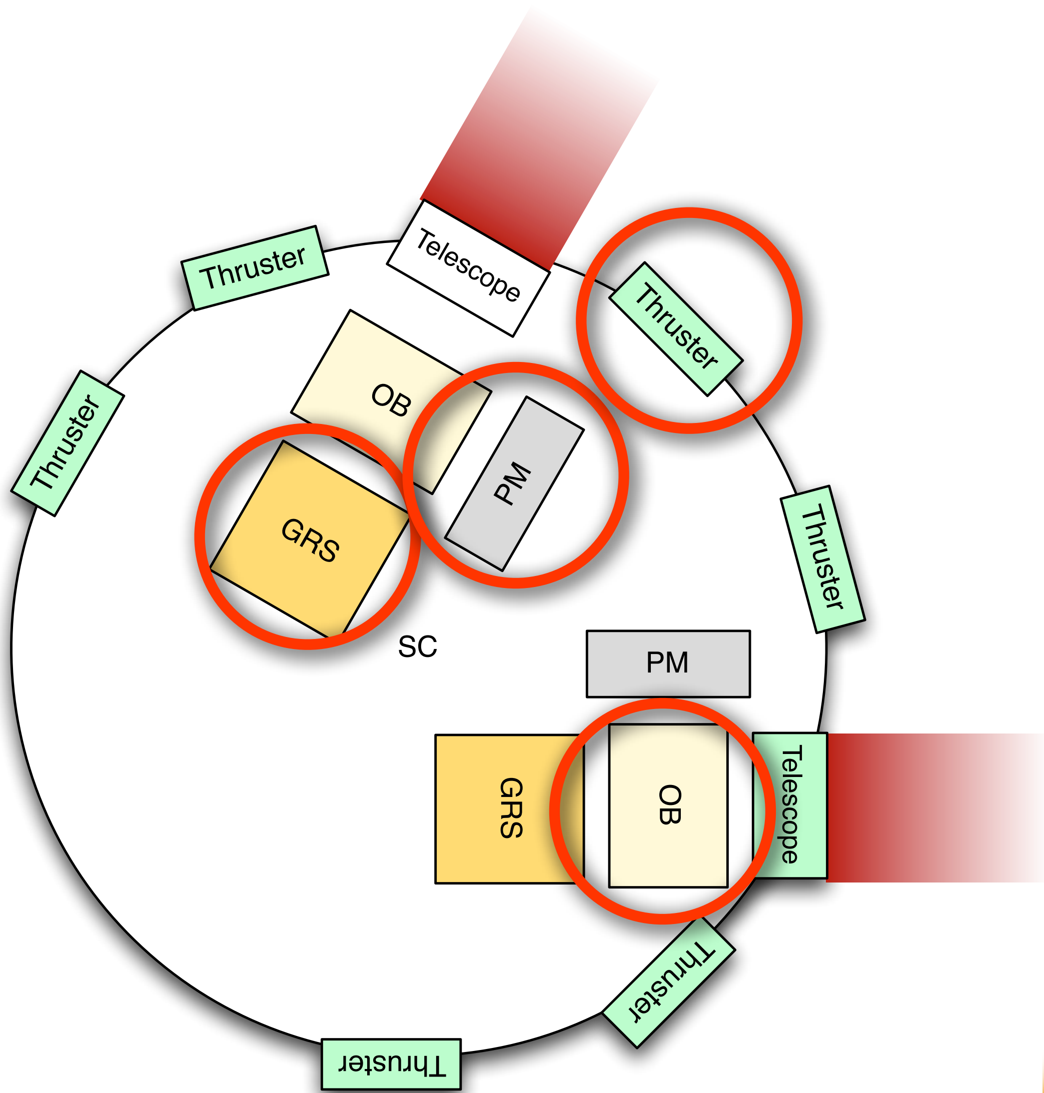
M Hewitson for the LPF team

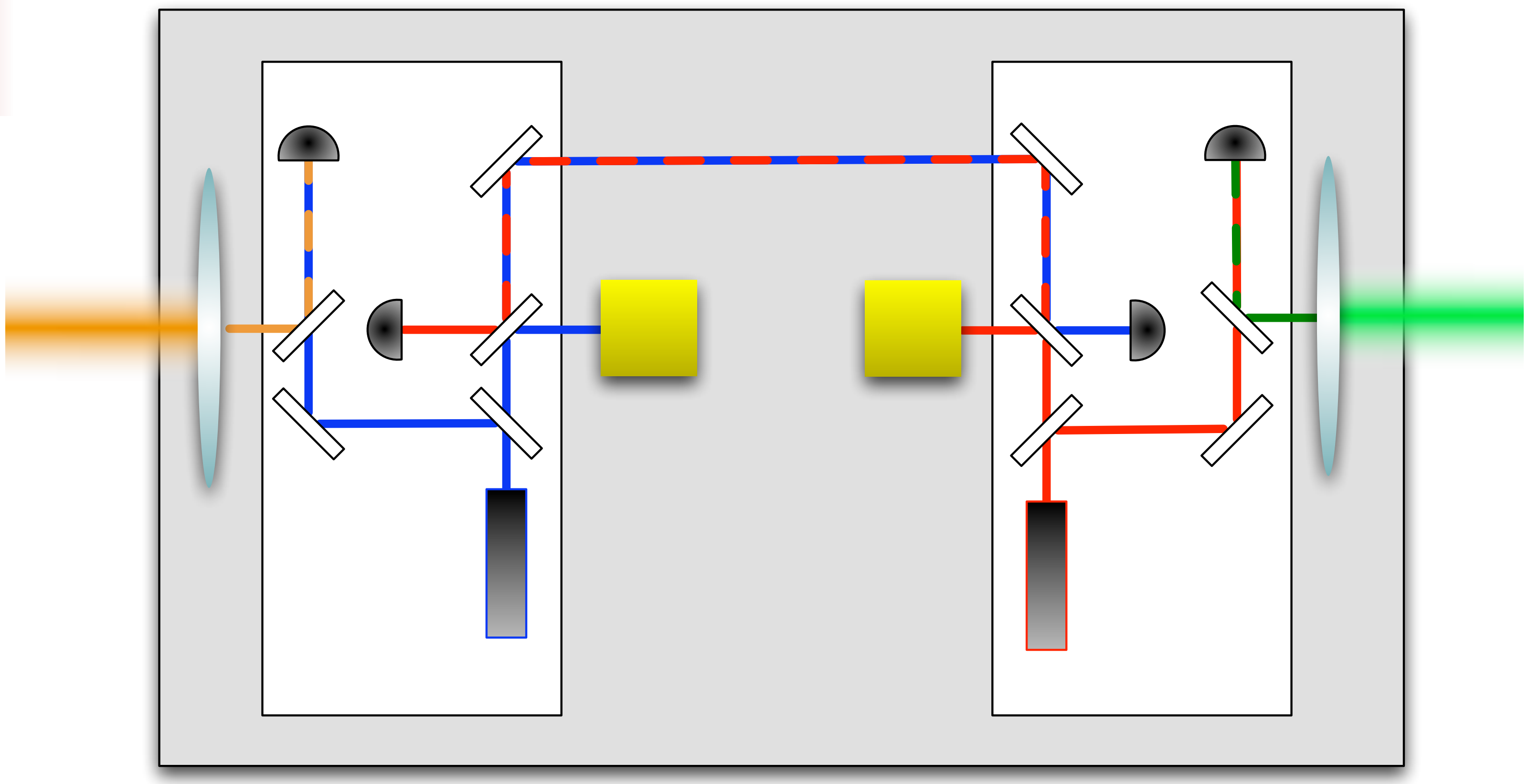
GWADW, May 24th 2011

LISA Measurement -> LPF



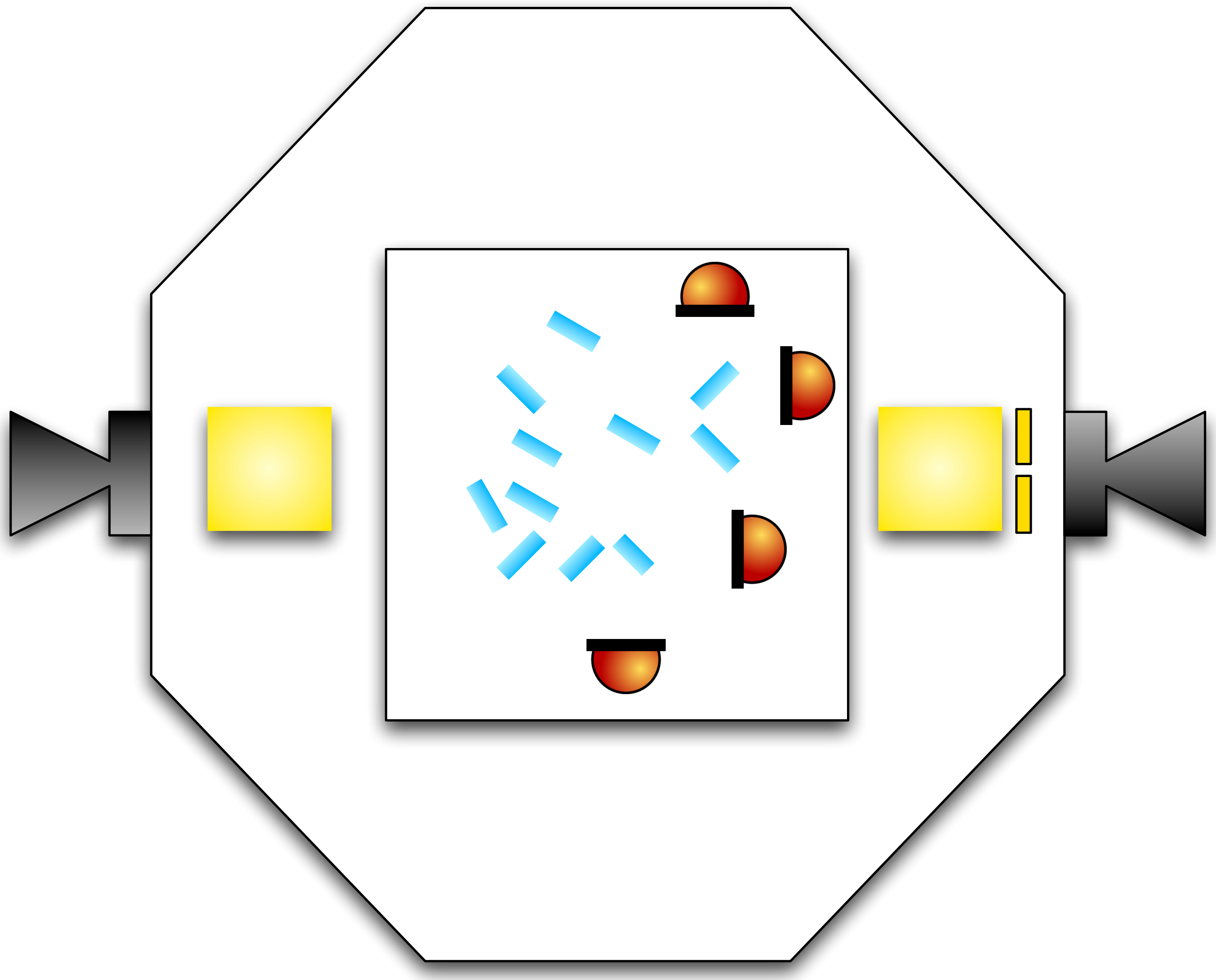




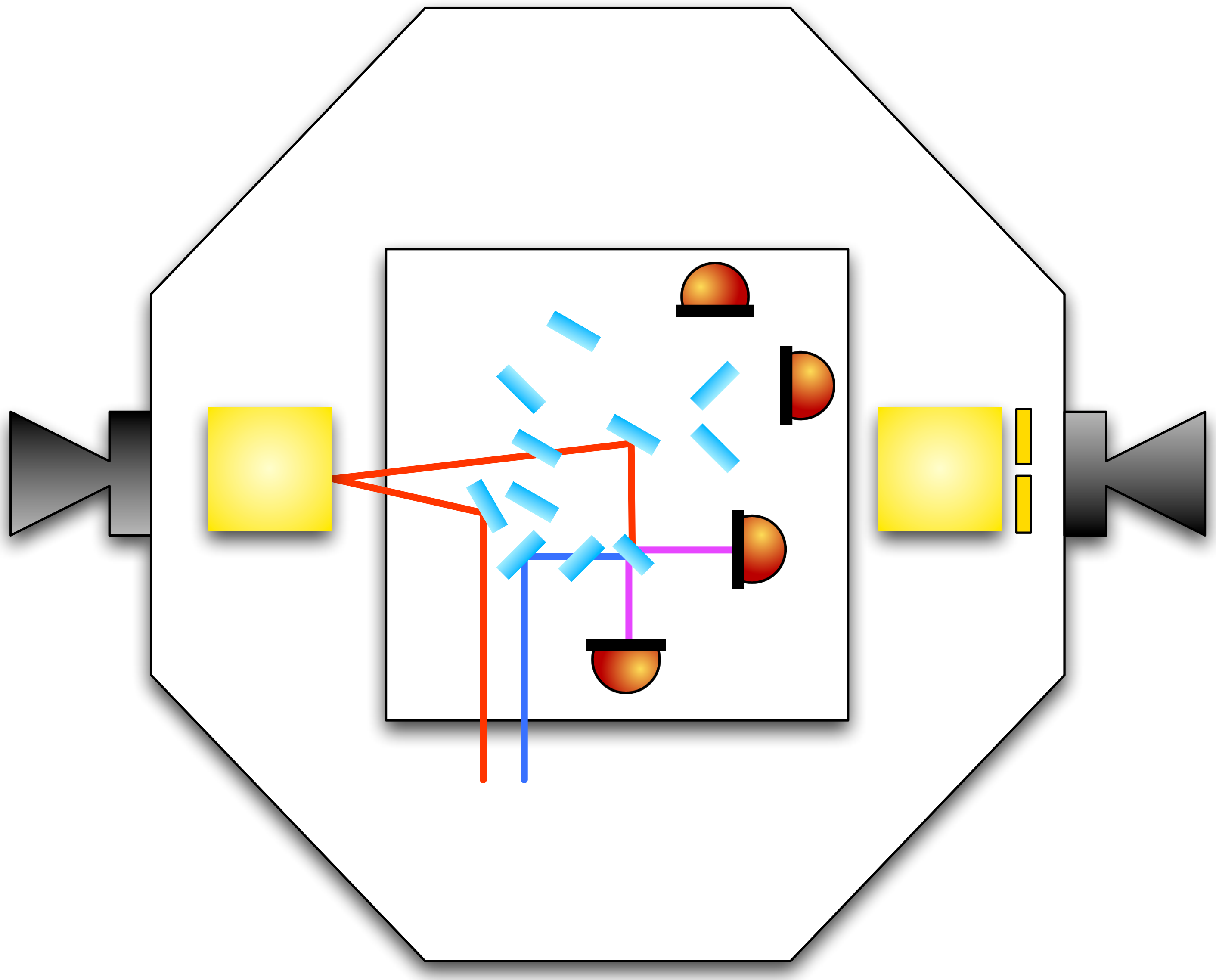


Tuesday, May 24, 2011

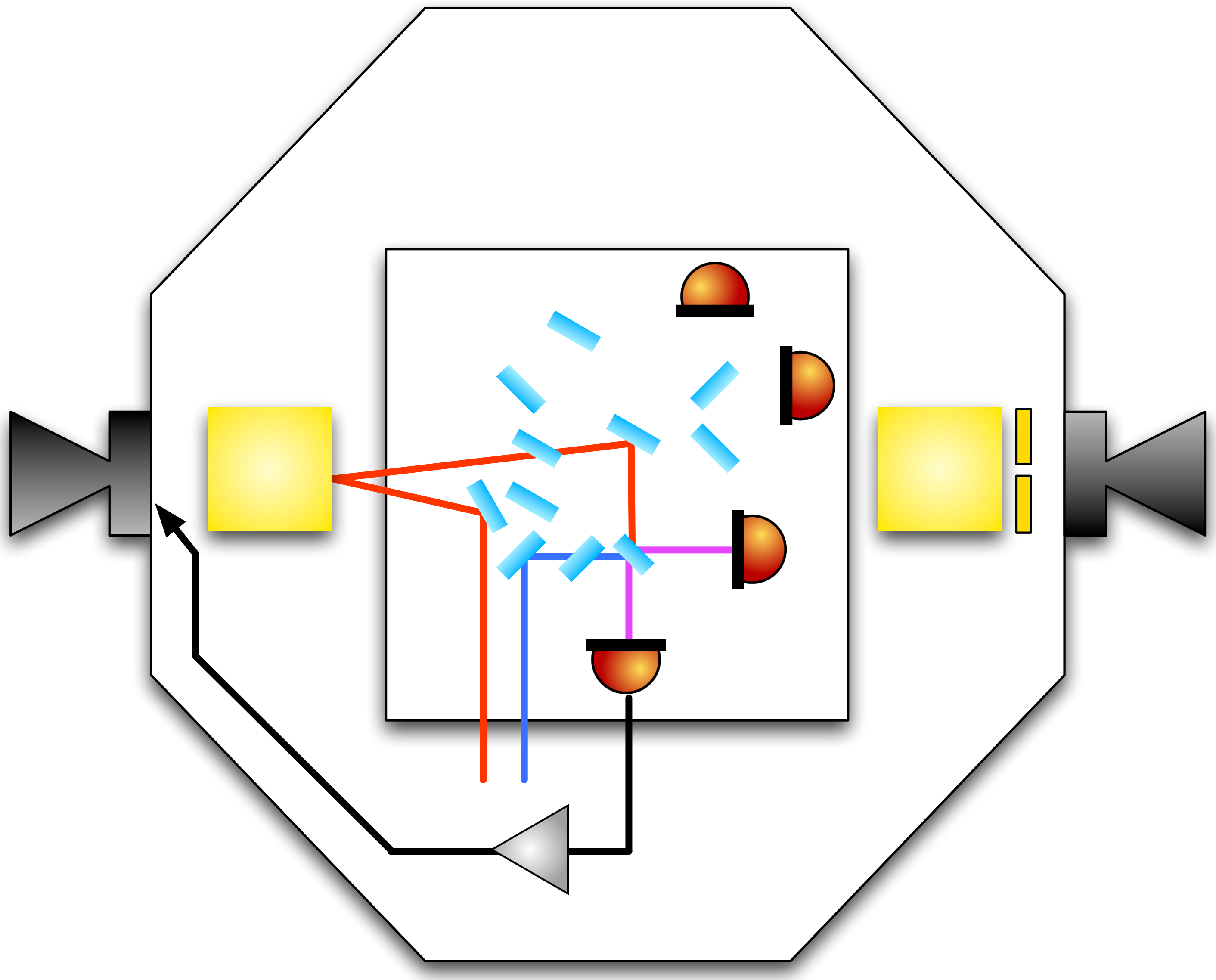
LPF *x*-axis measurement



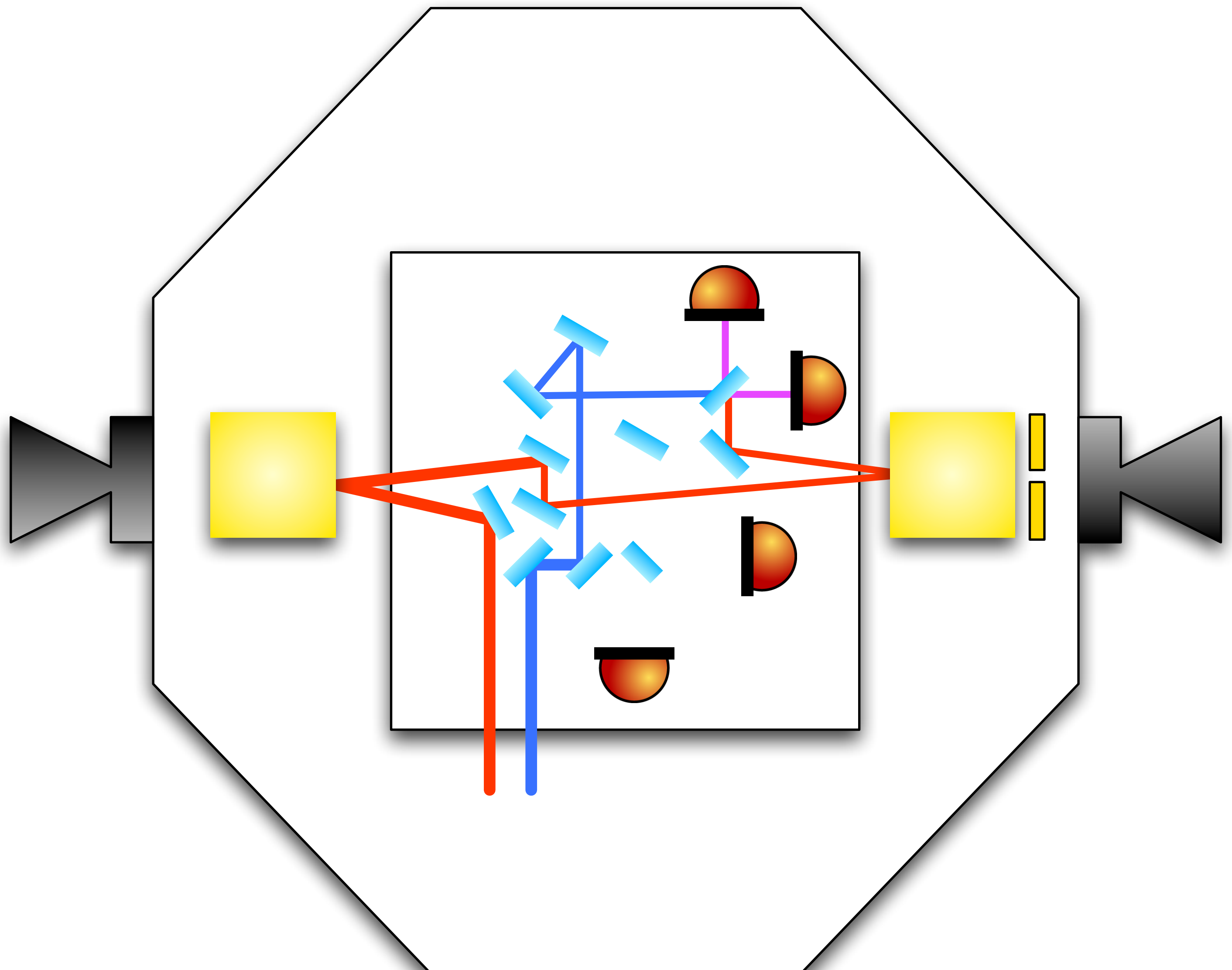
IFO X1: SC-TM1 measurement



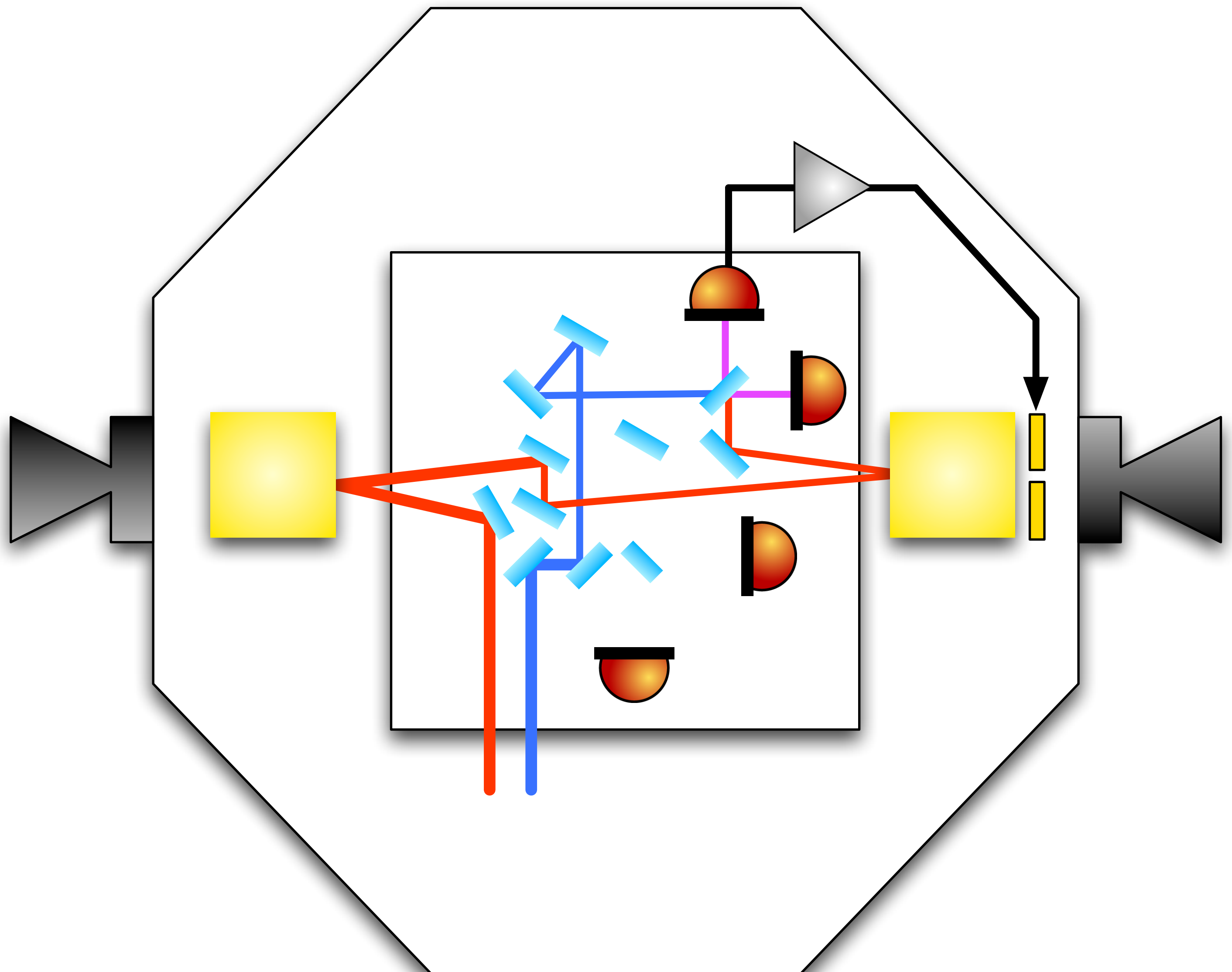
Drag-free on TM1



IFO X12: TM1-TM2 displacement



Suspension control



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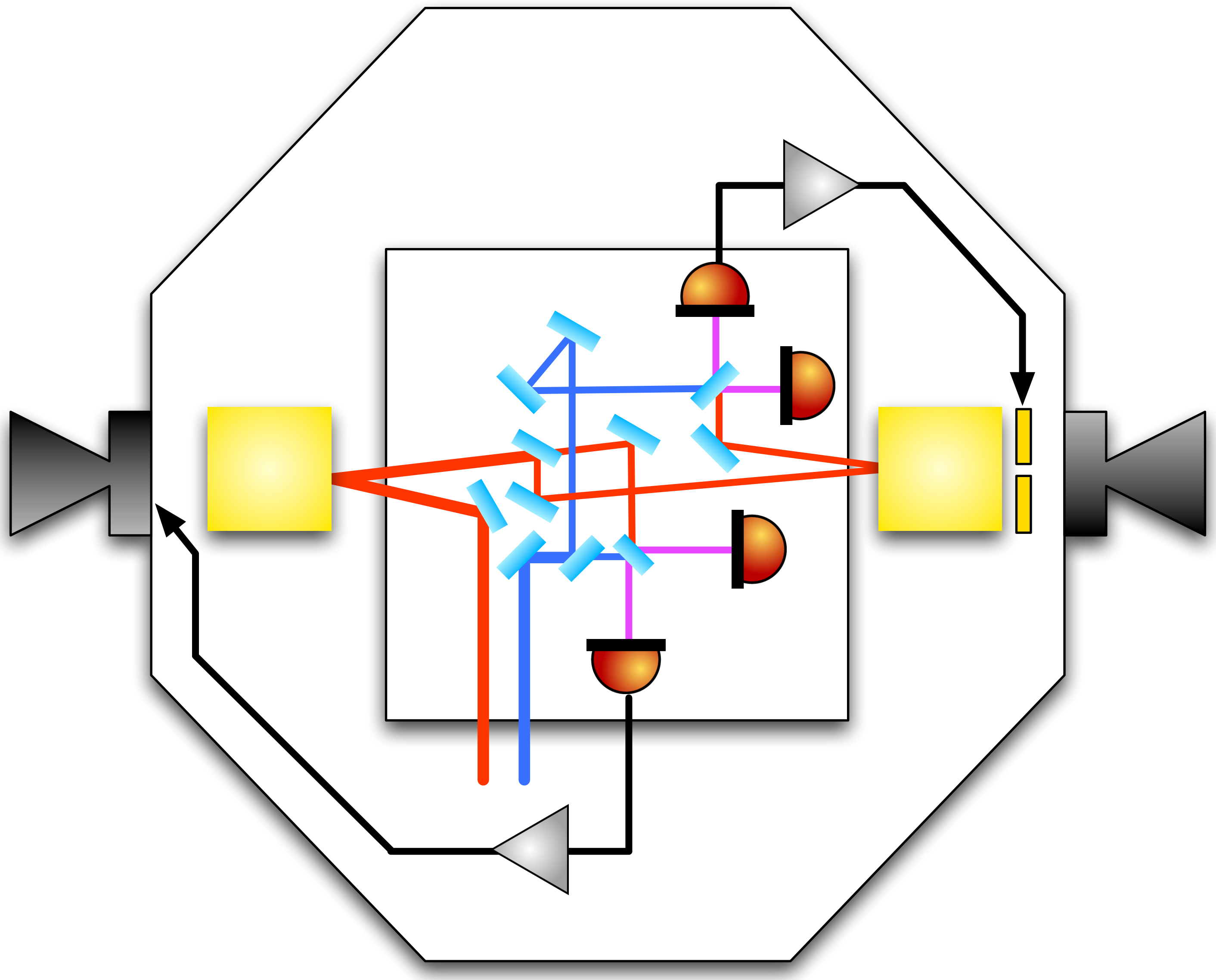

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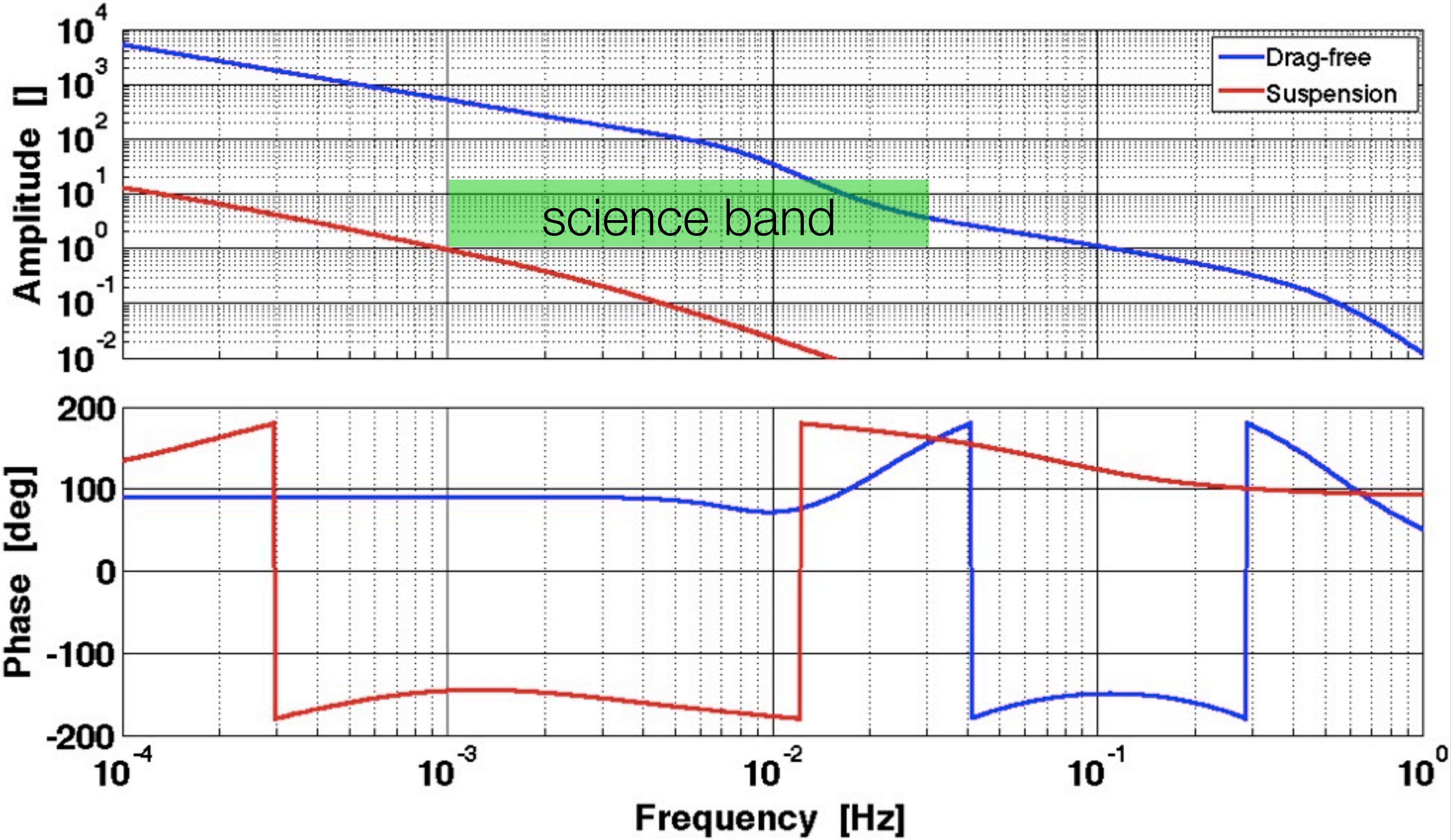

The LPF Mission

- Technology demonstrator for LISA:
  - micro-Newton propulsion
  - Gravitational Reference Sensor
  - Interferometric techniques
  - Drag-free control
- Requirements relaxed
  - 1 order of magnitude in differential acceleration
  - 1 order of magnitude higher frequency

The LPF Mission

- Technology demonstrator for LISA:
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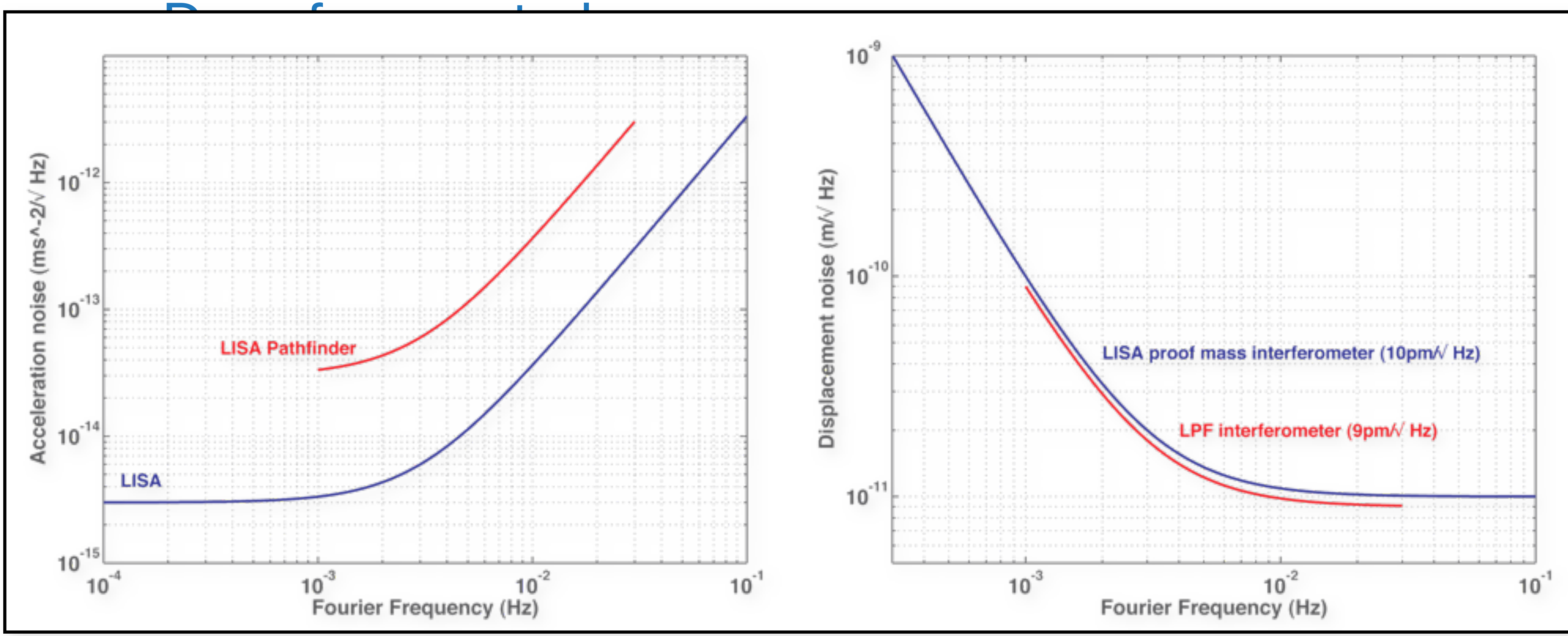
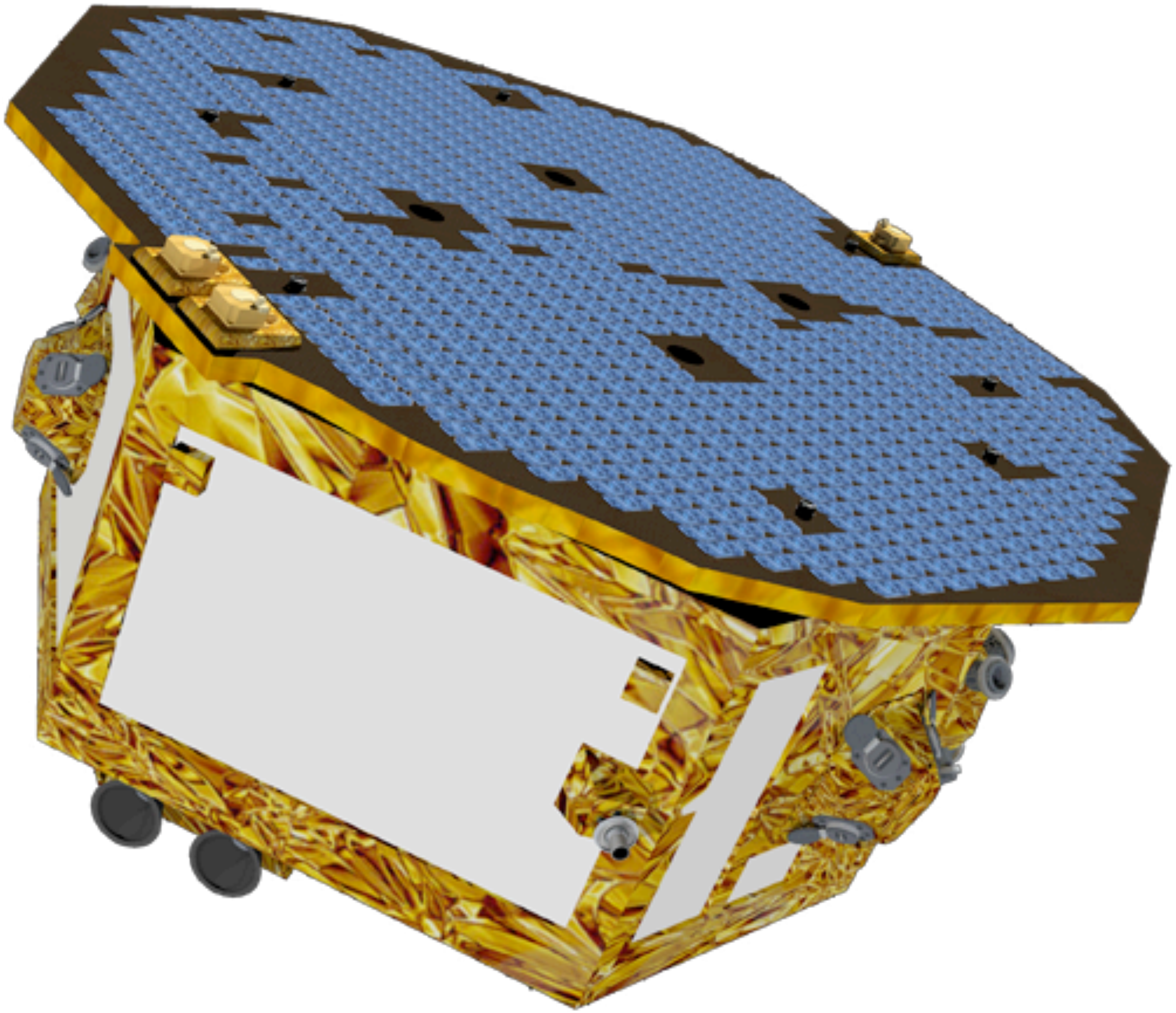
  - Gravitational Reference Sensor
  - Interferometric techniques



Spacecraft



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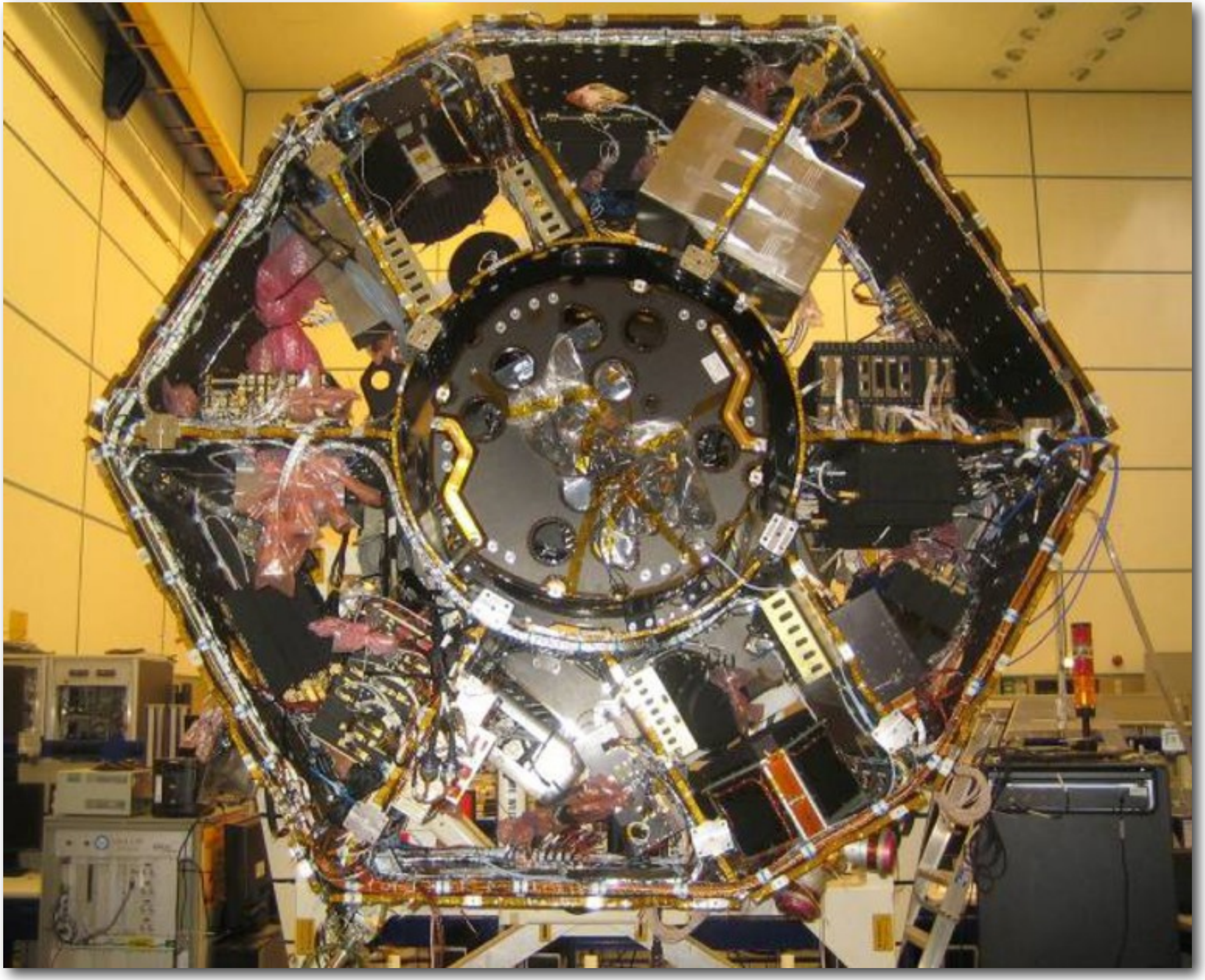

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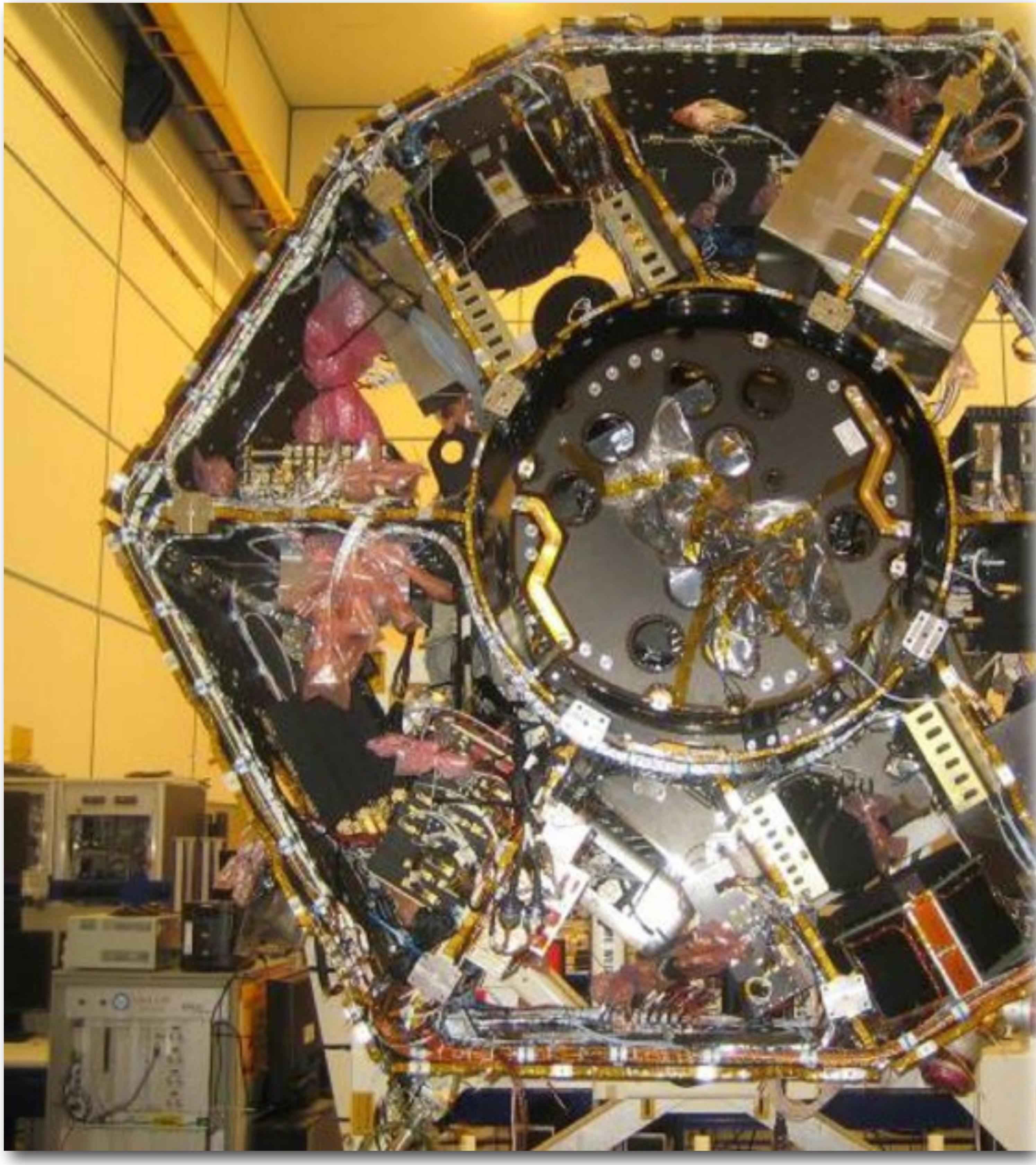
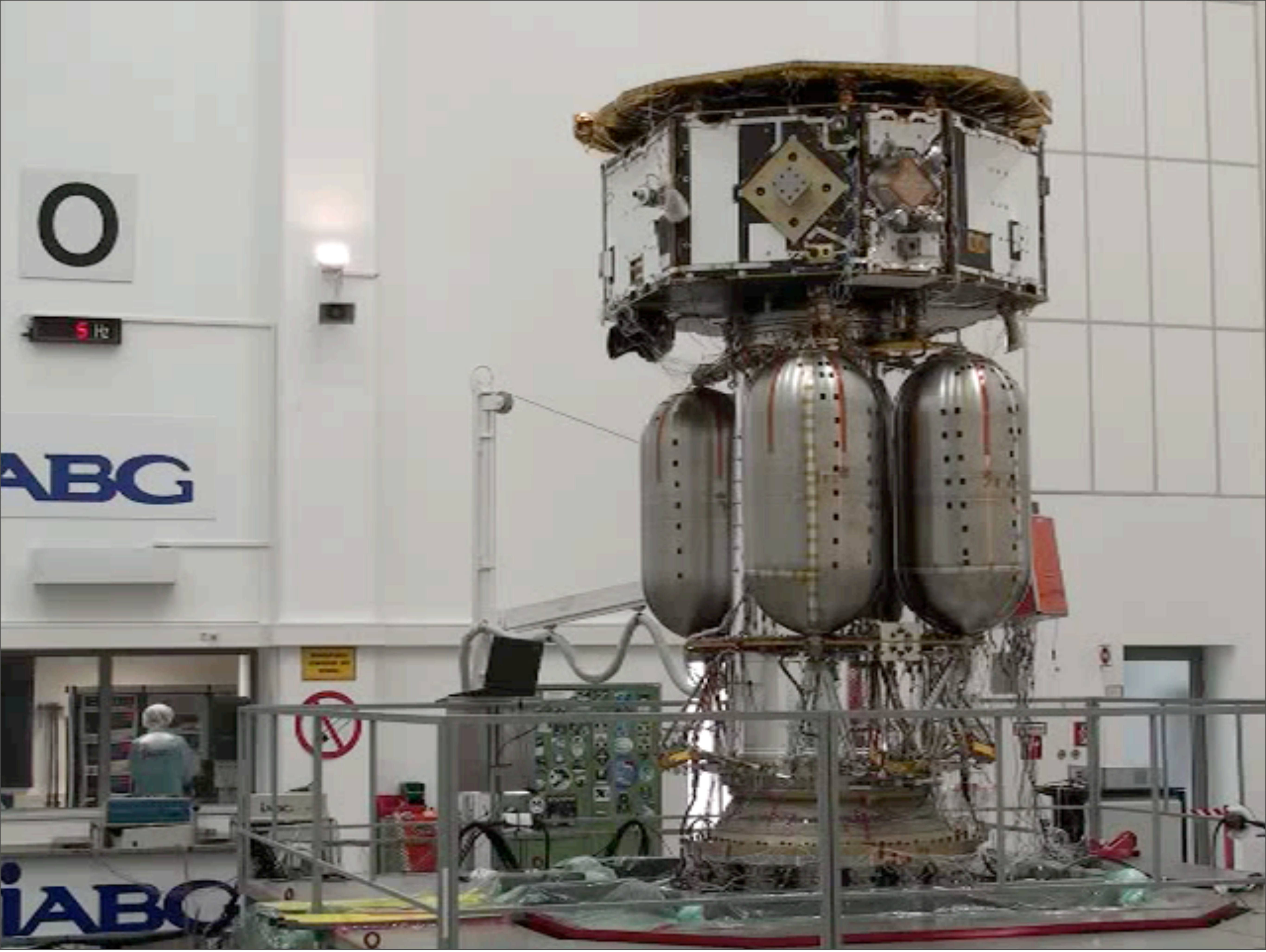


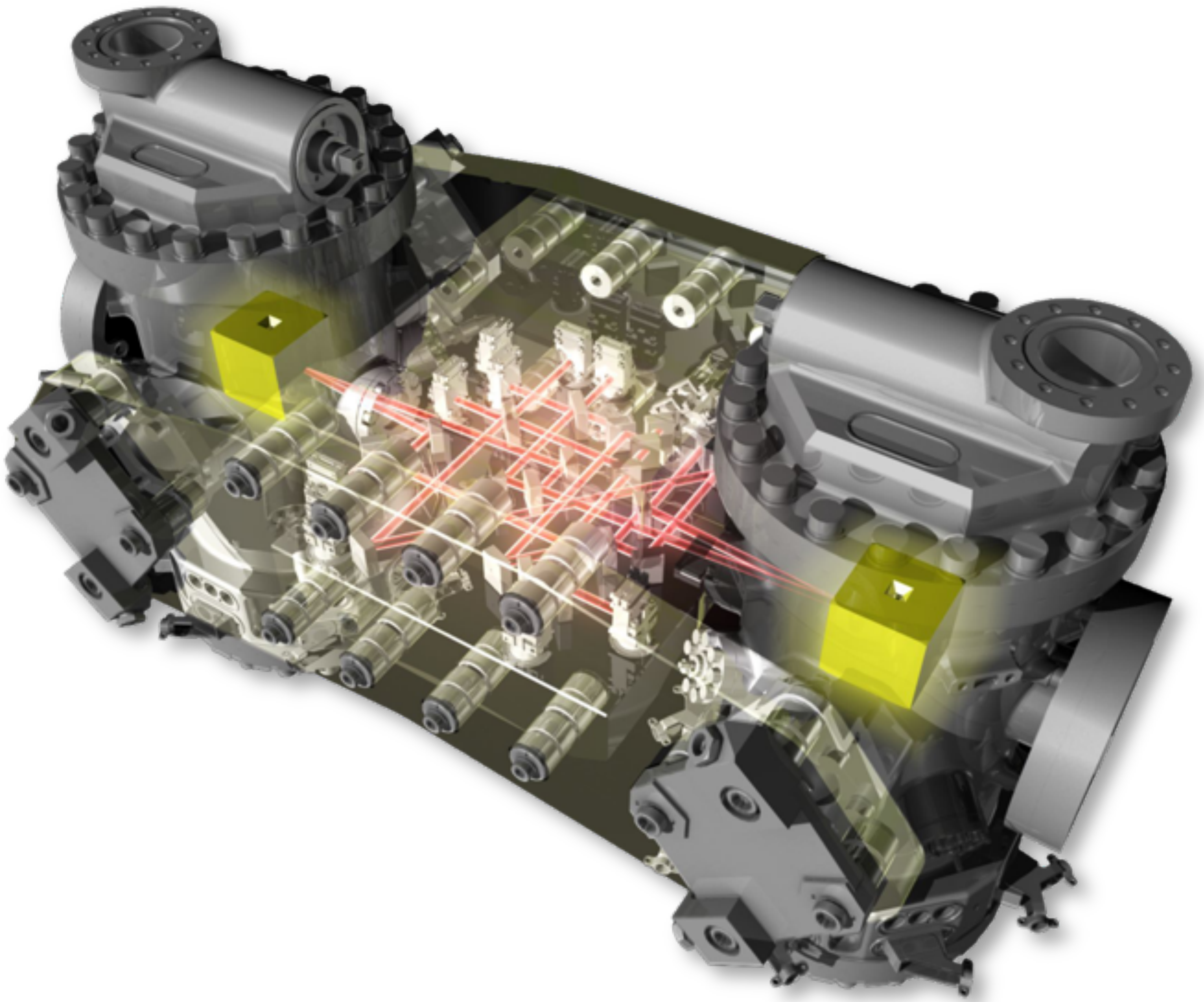

O
5 Hz
ABG

Payload(s)

- The LISA Technology Package
  - European payload
  - Full system
    - thrusters, test-masses, inertial sensor, interferometers, etc

- The Disturbance Reduction System
  - NASA payload
  - Alternative thrusters
  - Alternative drag-free control

The LTP



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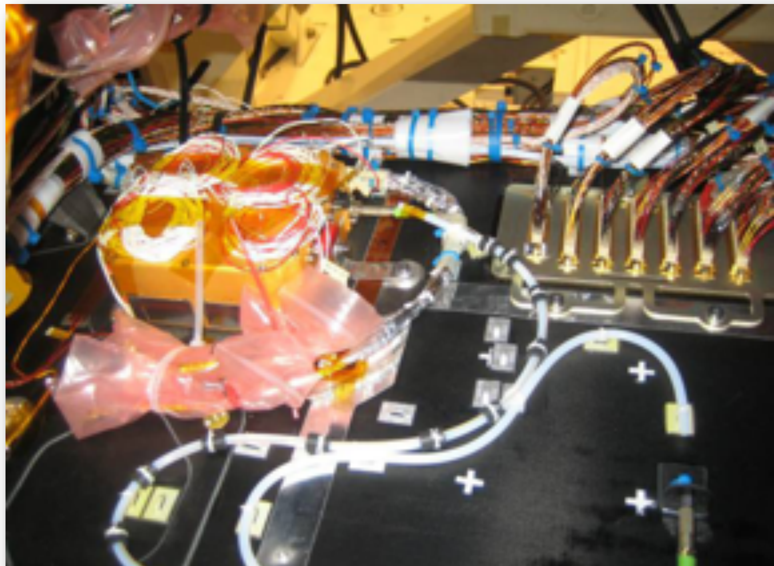
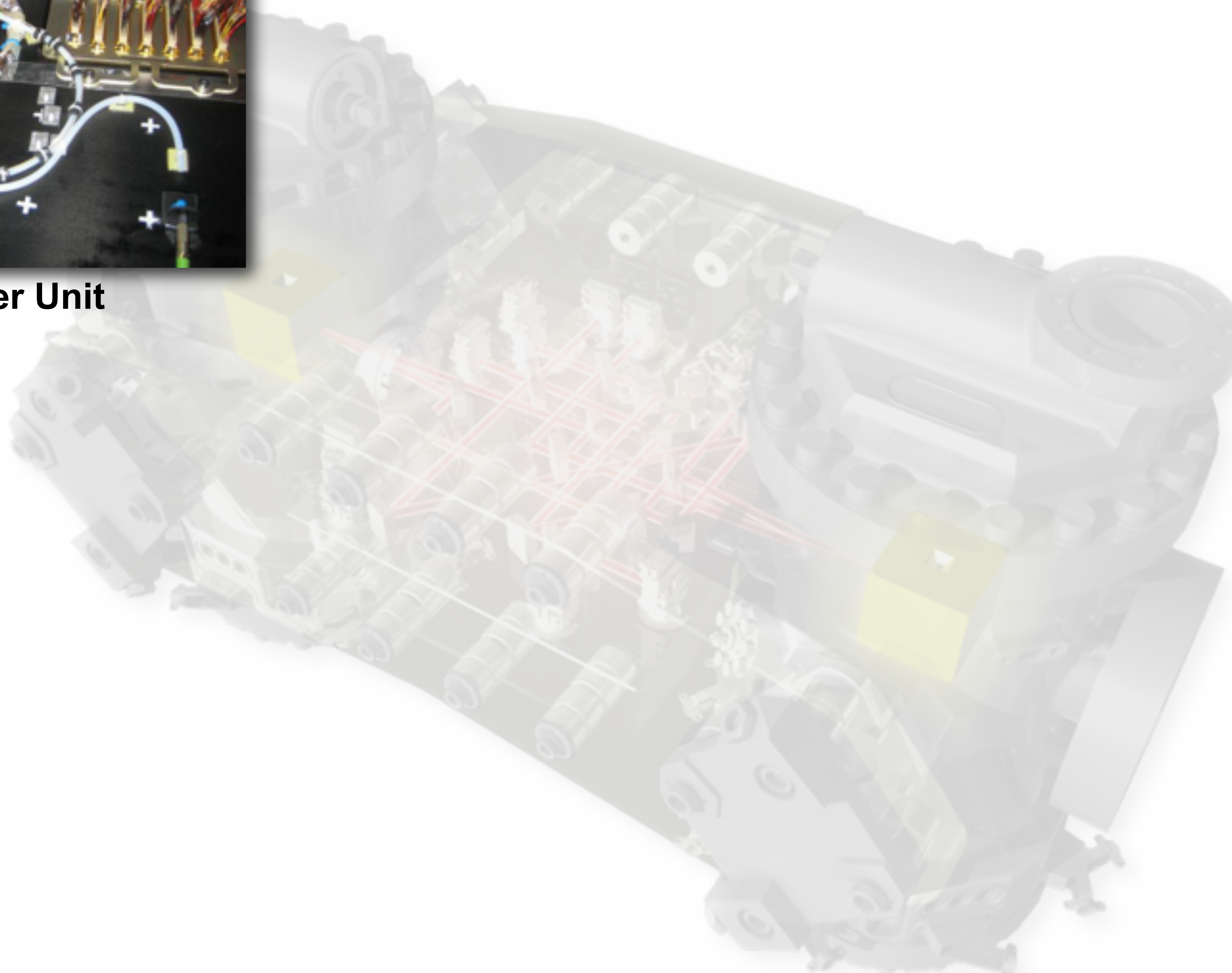


Reference Laser Unit



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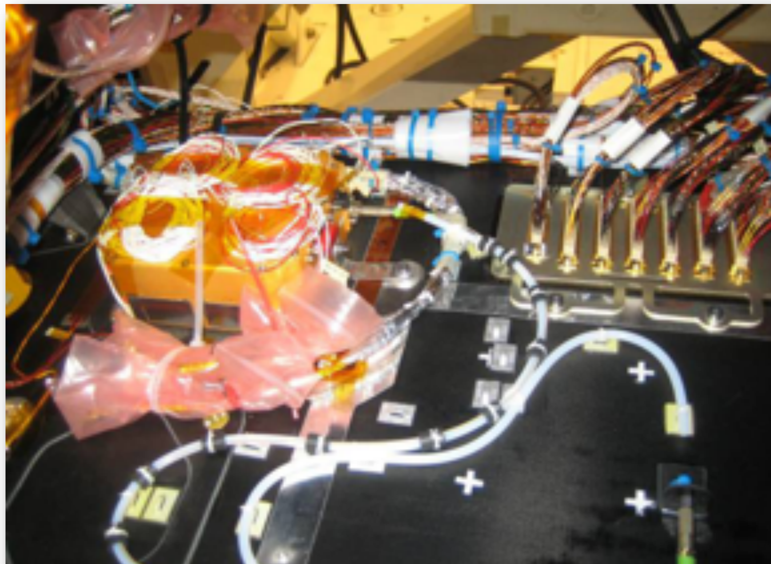

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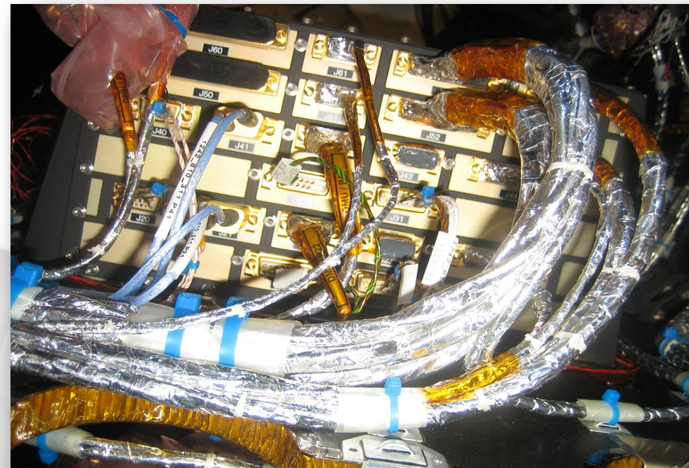
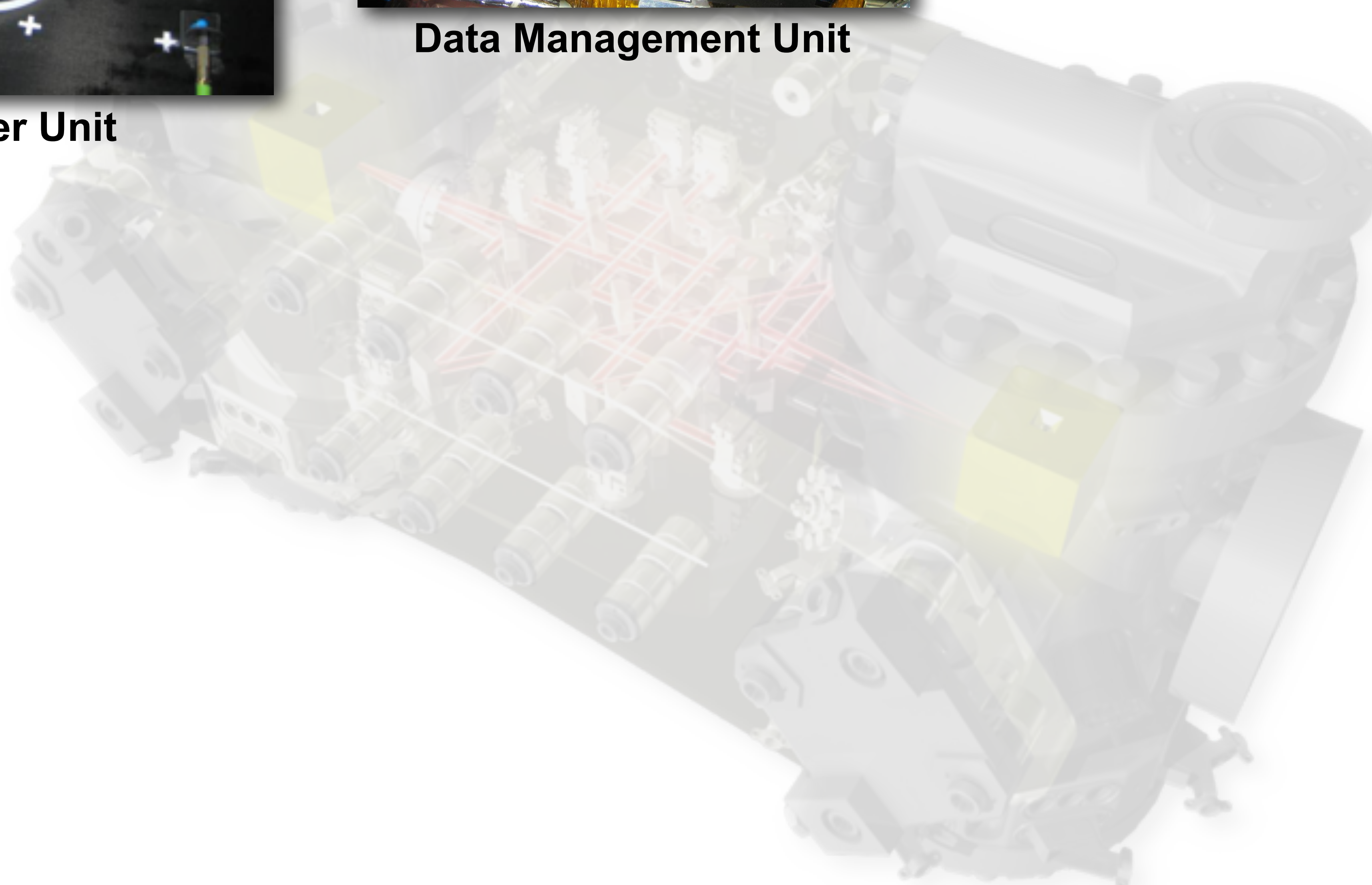


Data Management Unit



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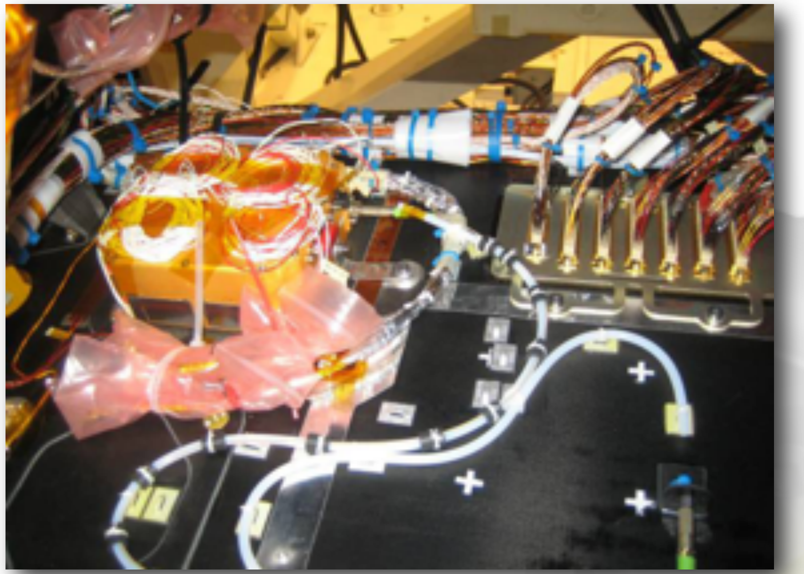

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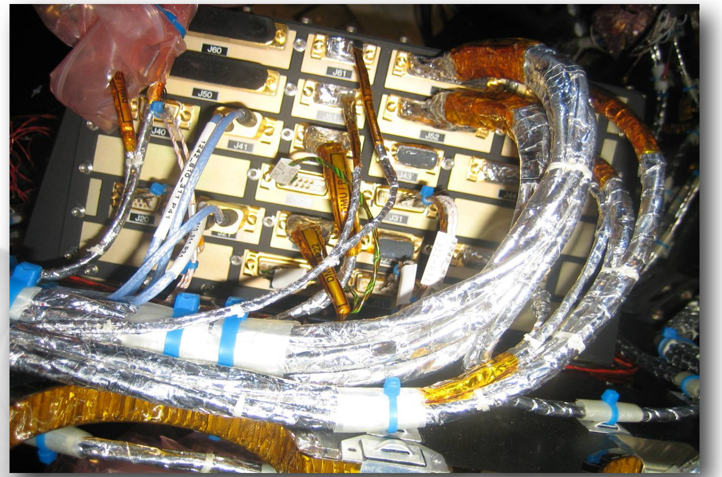

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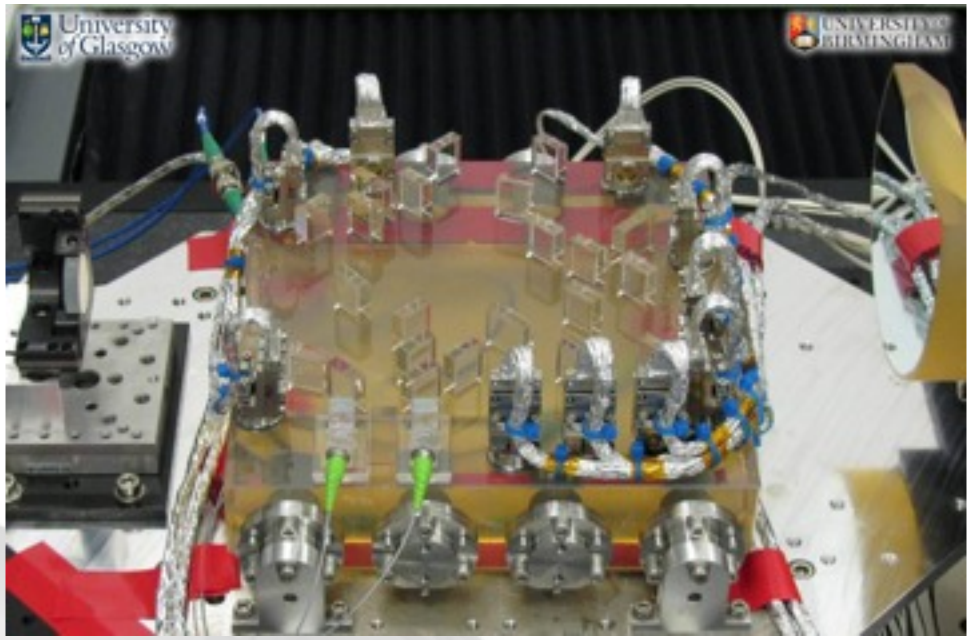
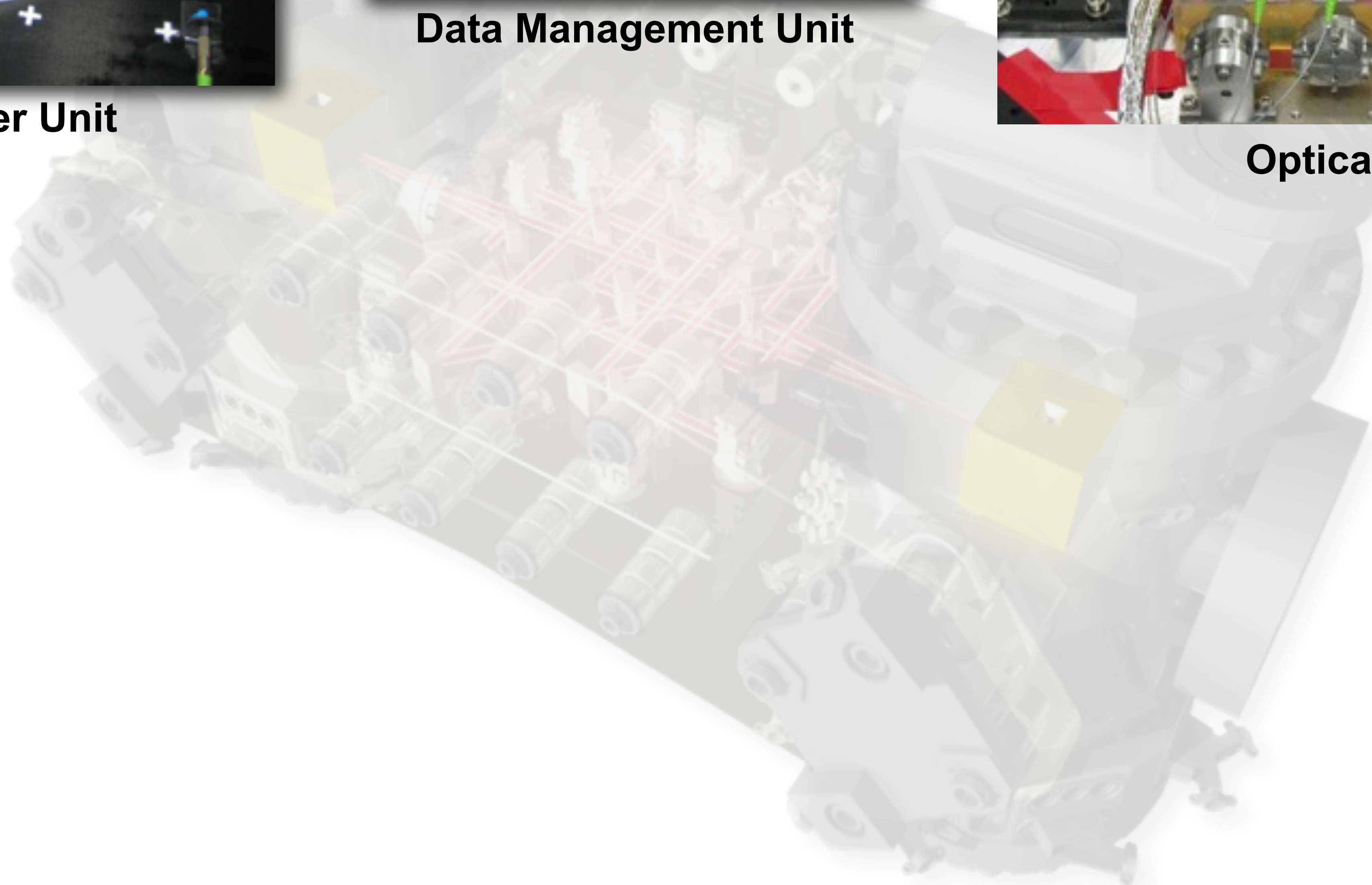


Optical Bench



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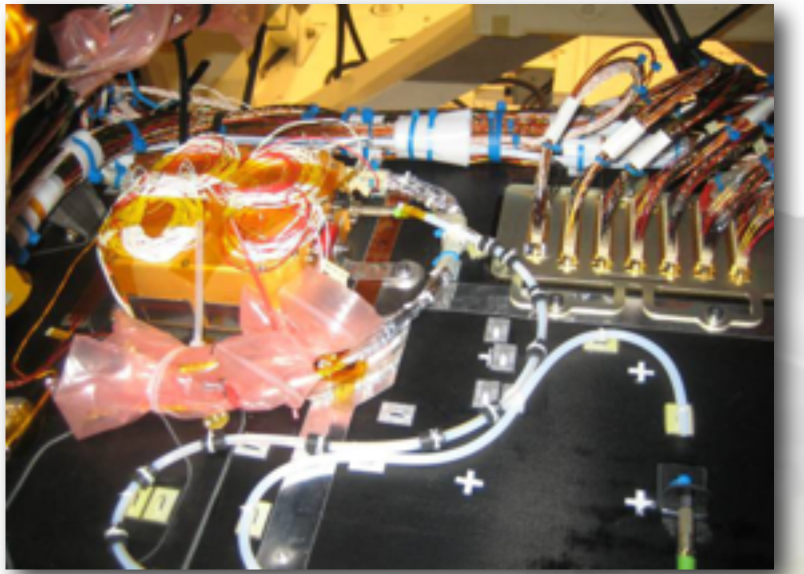

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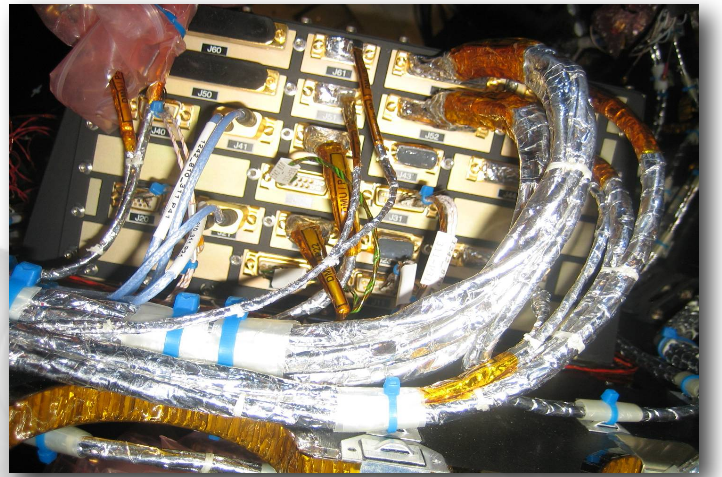

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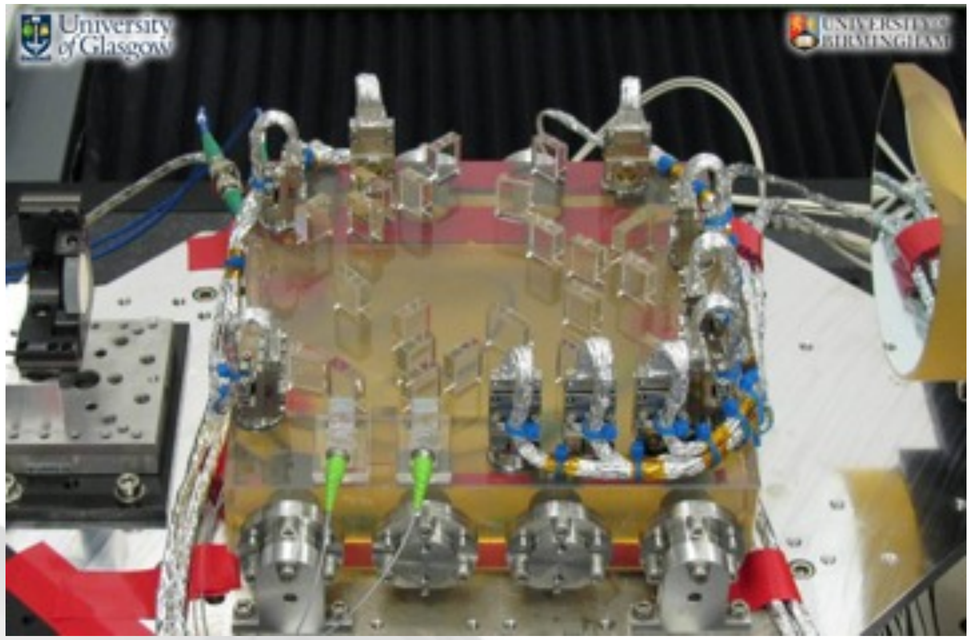

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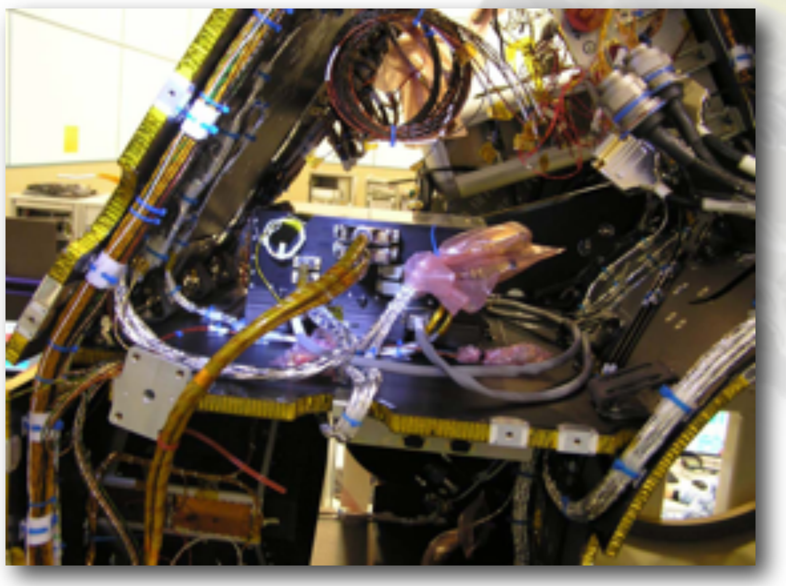
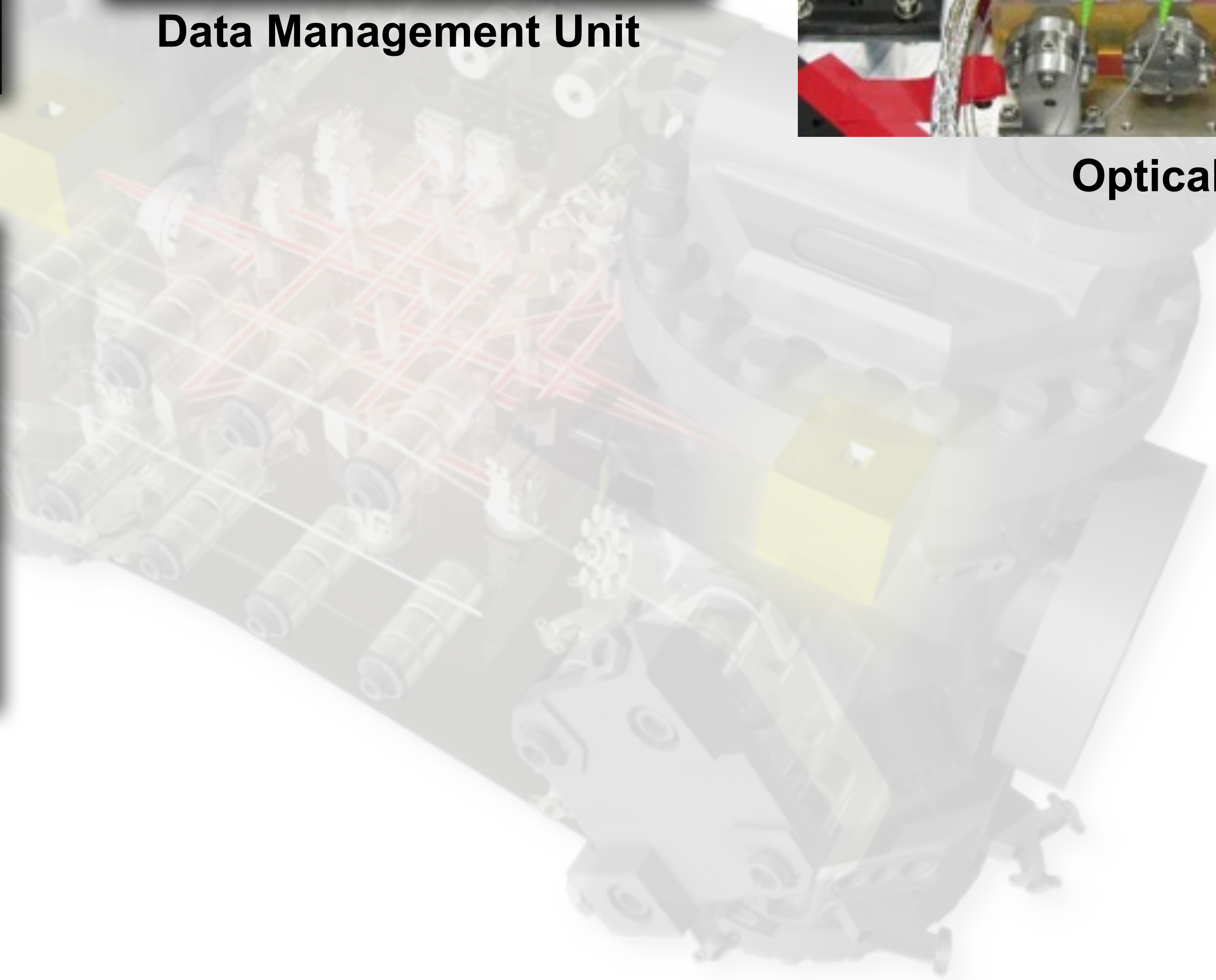


Phasemeter



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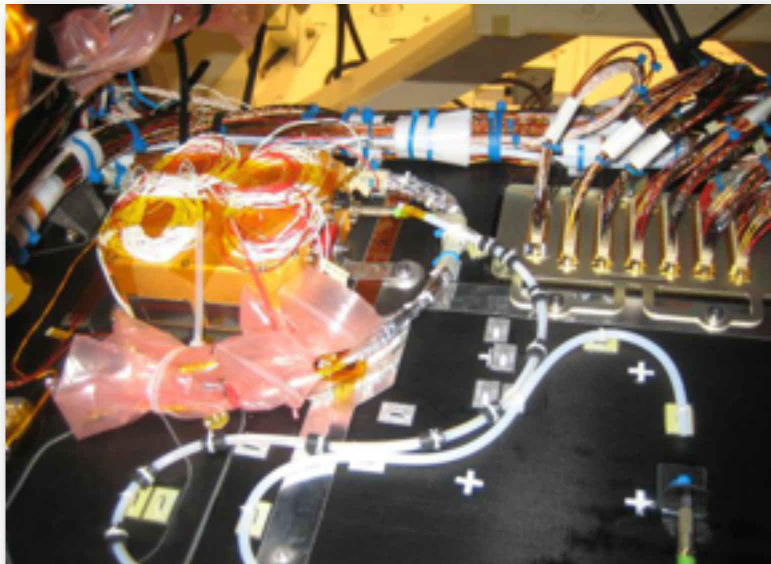

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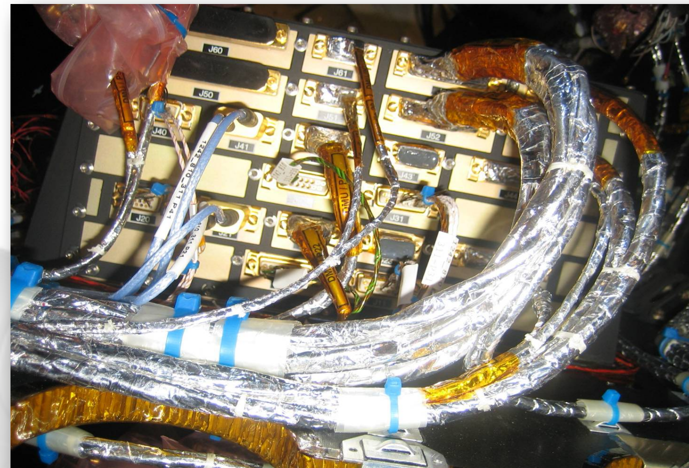

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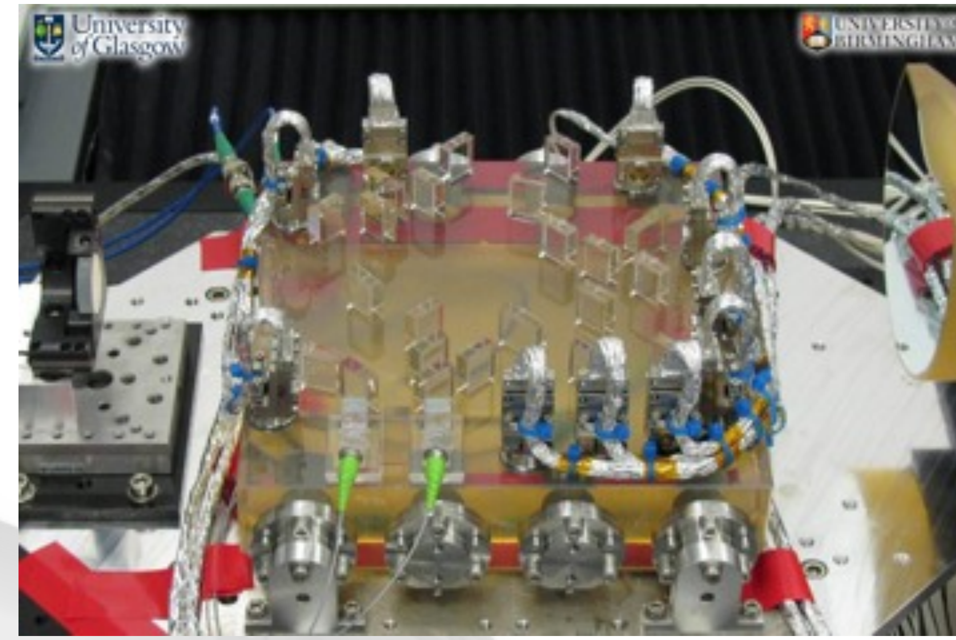

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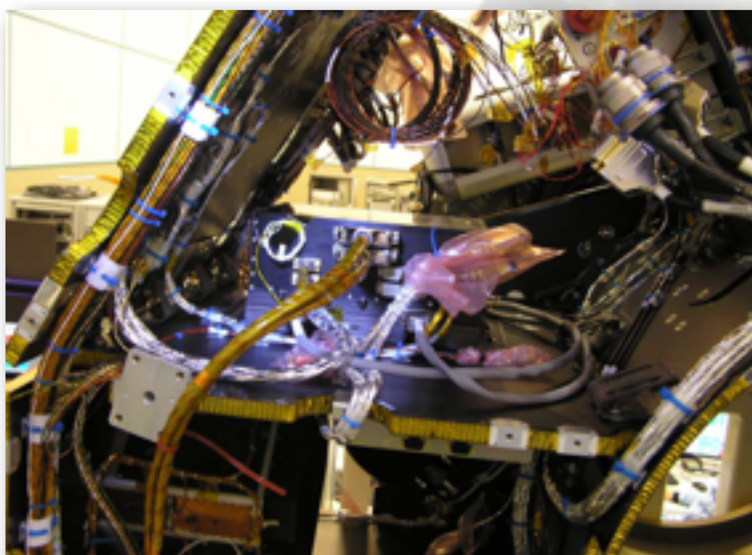

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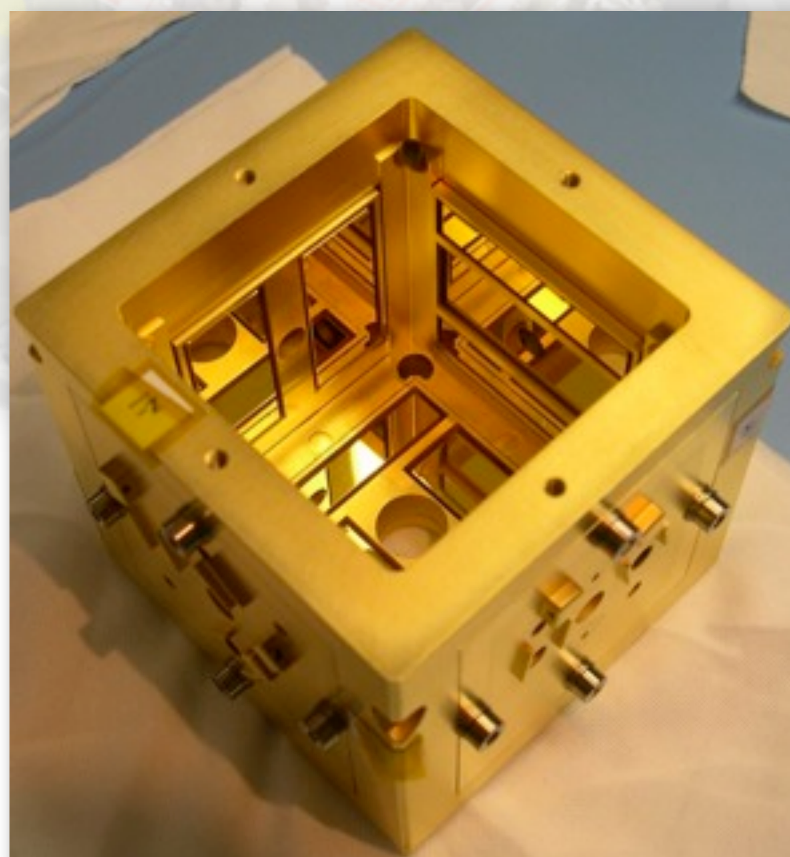
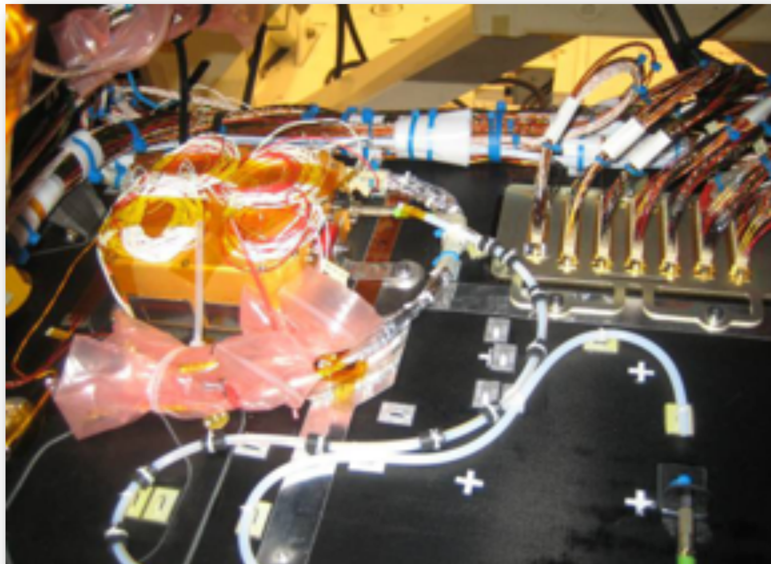


Inertial Sensor

The LTP



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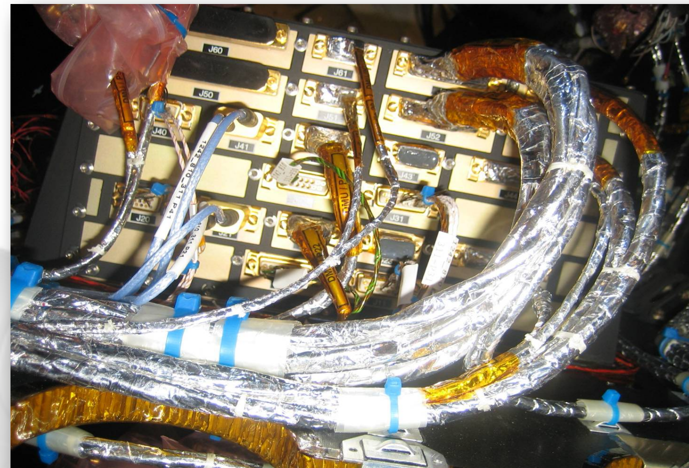

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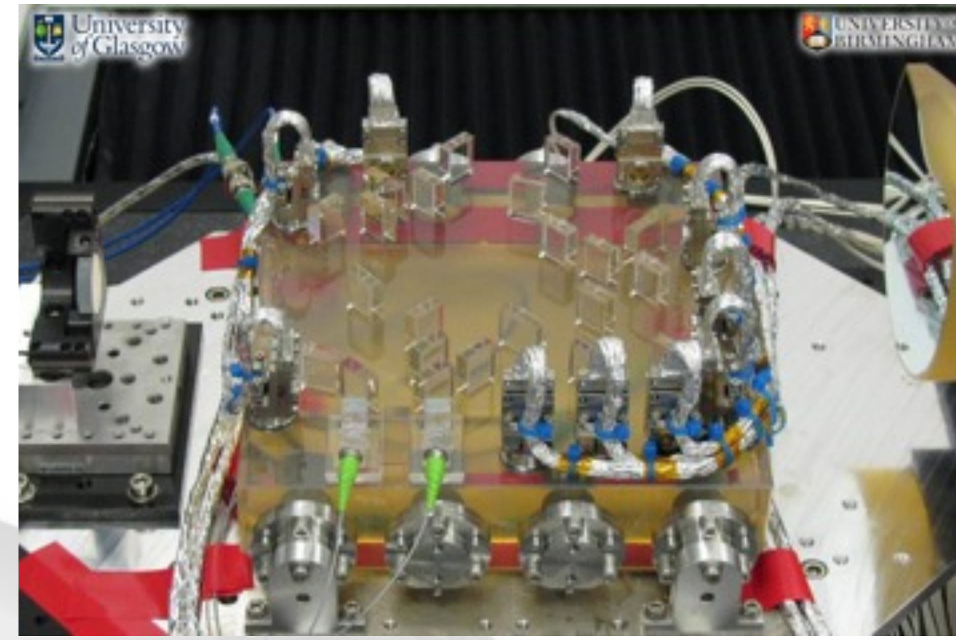

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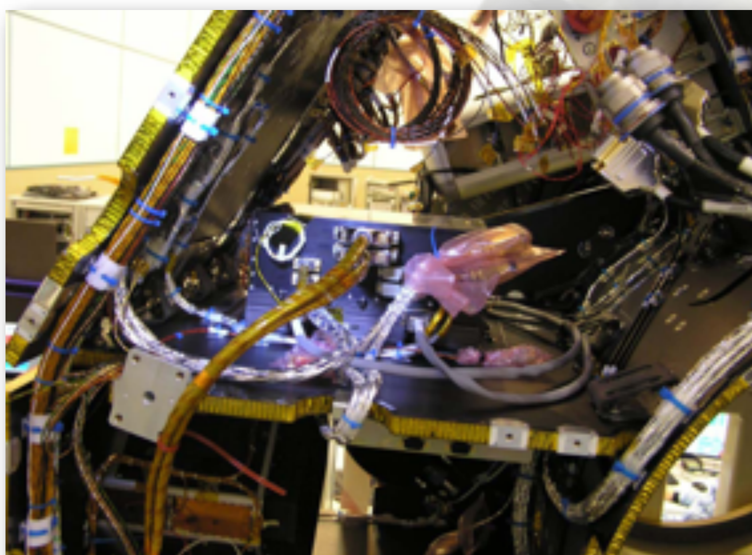

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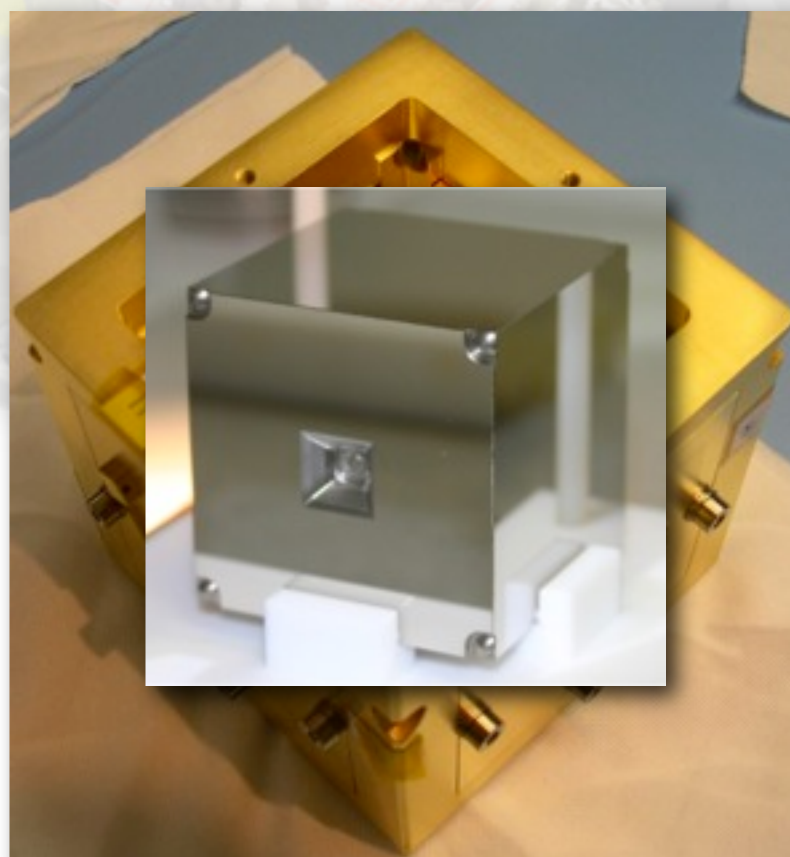

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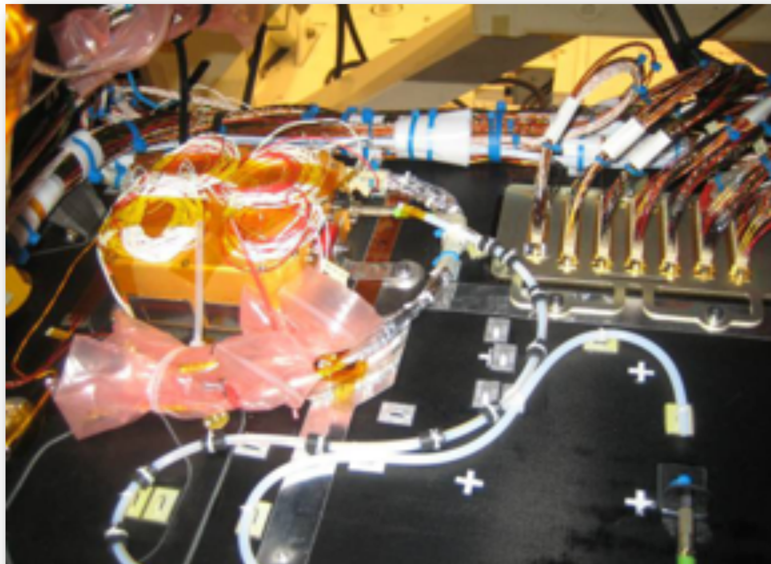

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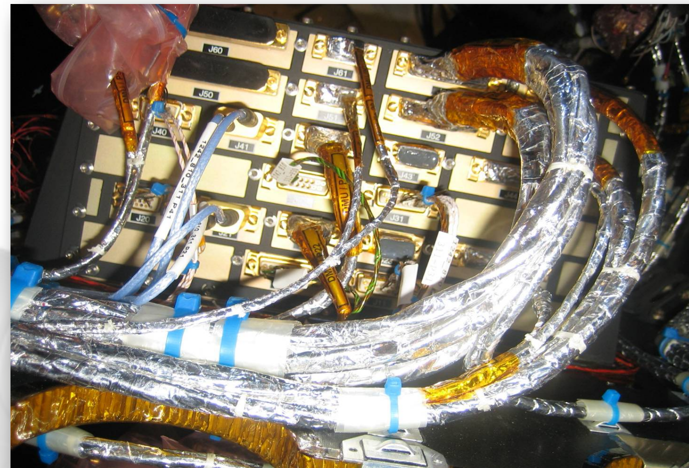

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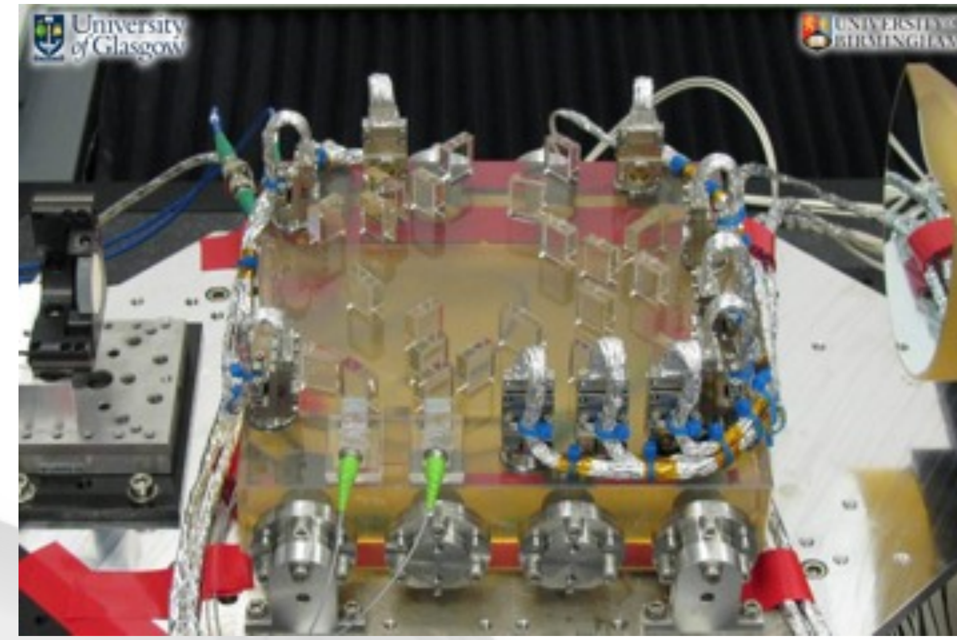

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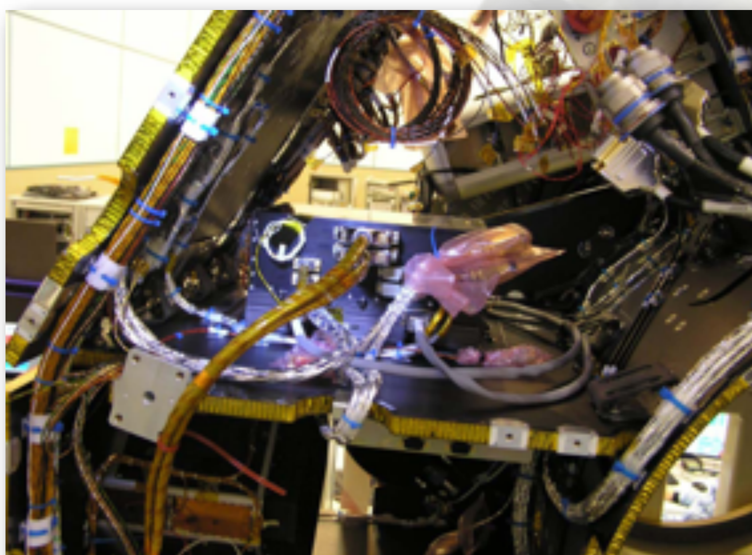

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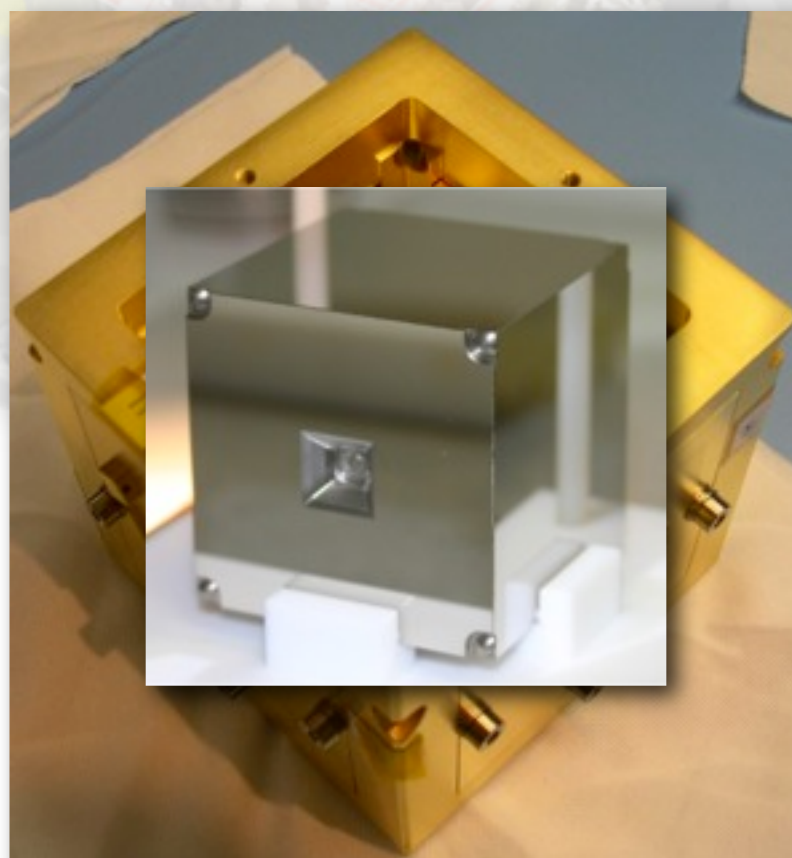
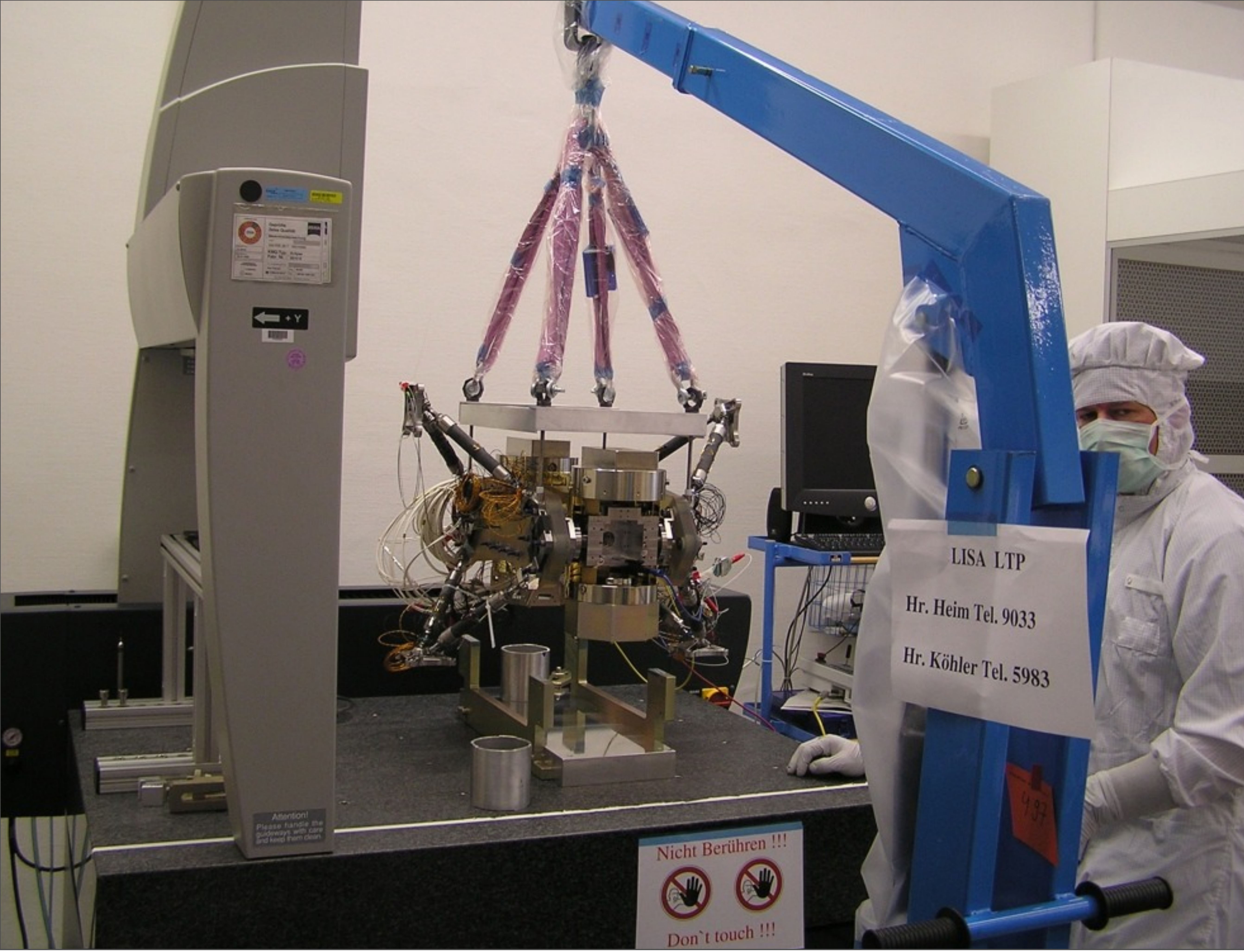


Inertial Sensor

Vacuum Enclosure

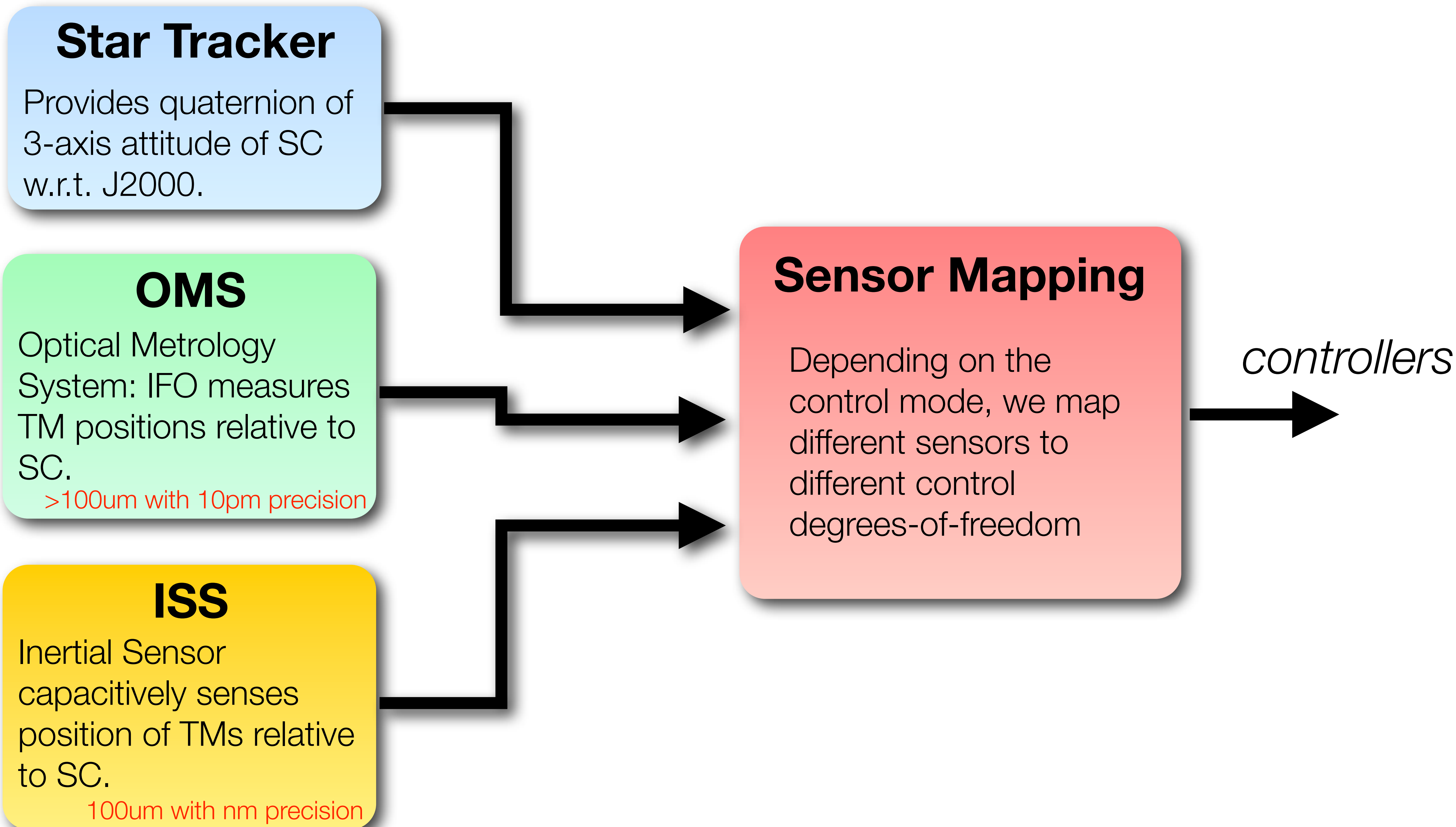

+Y
LISA LTP
Hr. Heim Tel. 9033
Hr. Köhler Tel. 5983
Attention!
Nicht Berühren !!!
Don`t touch !!!

What's missing?

- Micro-propulsion system
  - problems with FEEPs in the past
    - may now be solved
  - ESA currently looking at alternative systems

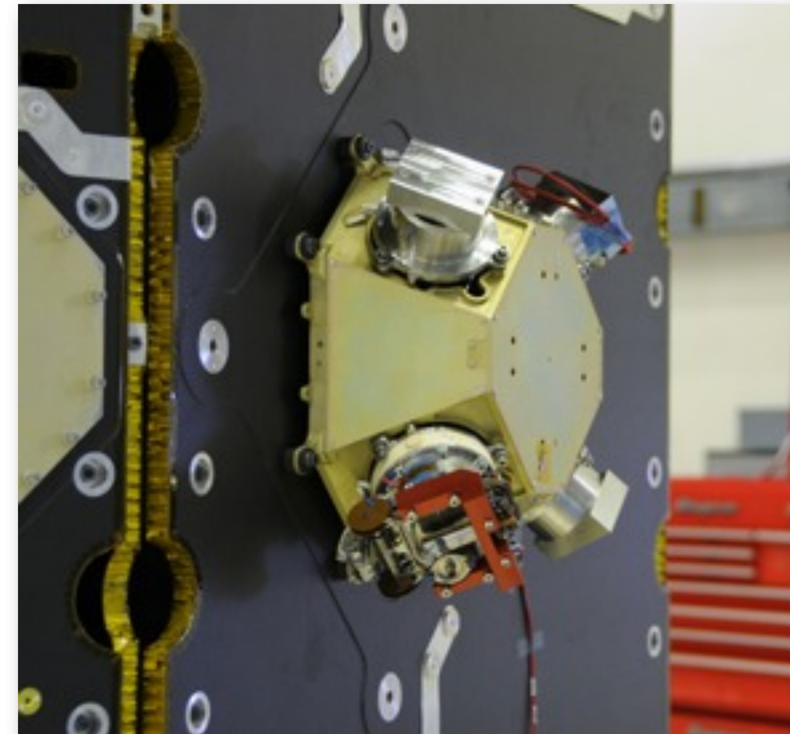
- Caging mechanism
  - Construction of original launch-lock proved challenging
  - ESA investigating alternatives

Sensing


Star Tracker
Provides quaternion of 3-axis attitude of SC w.r.t. J2000.
OMS
Optical Metrology System: IFO measures TM positions relative to SC.
>100um with 10pm precision
ISS
Inertial Sensor capacitively senses position of TMs relative to SC.
100um with nm precision
Sensor Mapping
Depending on the control mode, we map different sensors to different control degrees-of-freedom
controllers

Actuation

- Micro-propulsion (FEEPs)
  - 6 d.o.f. of SC
  - 100uN thrust with uN accuracy



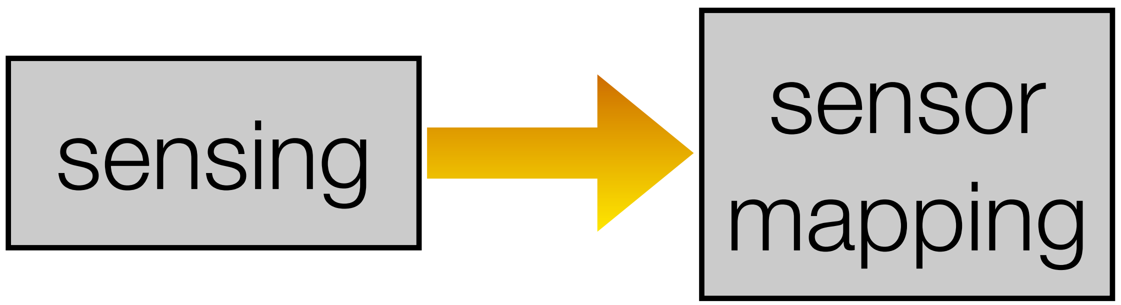
- Inertial Sensor
  - capacitive actuation
  - 6 d.o.f. per test-mass
  - wide-range: uN force with pN accuracy
  - high res.: nN force with fN accuracy

FEEP == Field Emission Electric Propulsion

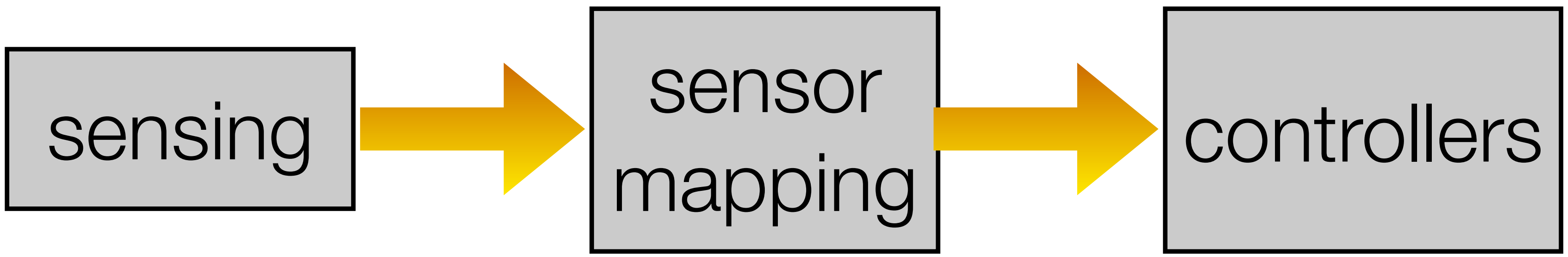
Control

sensing

Control



Control



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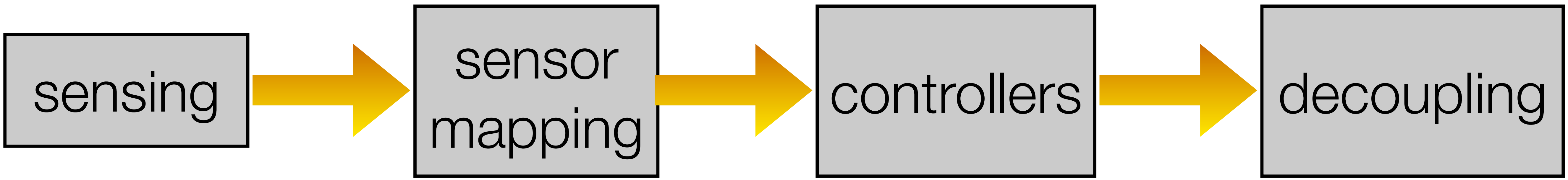

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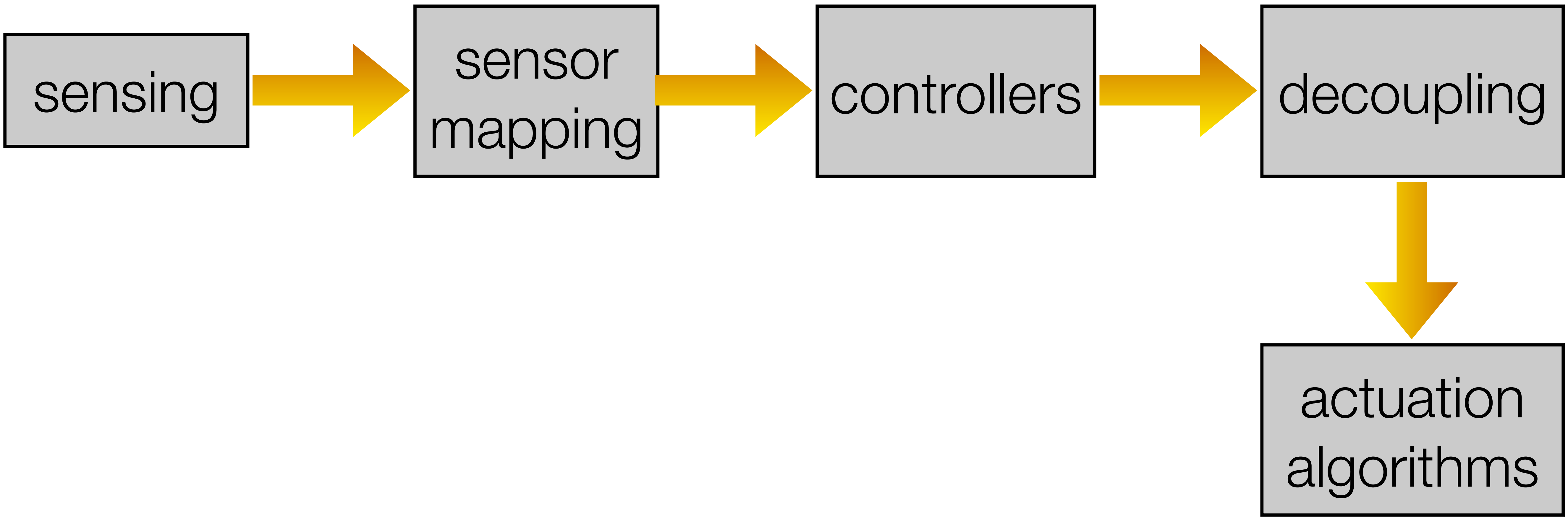
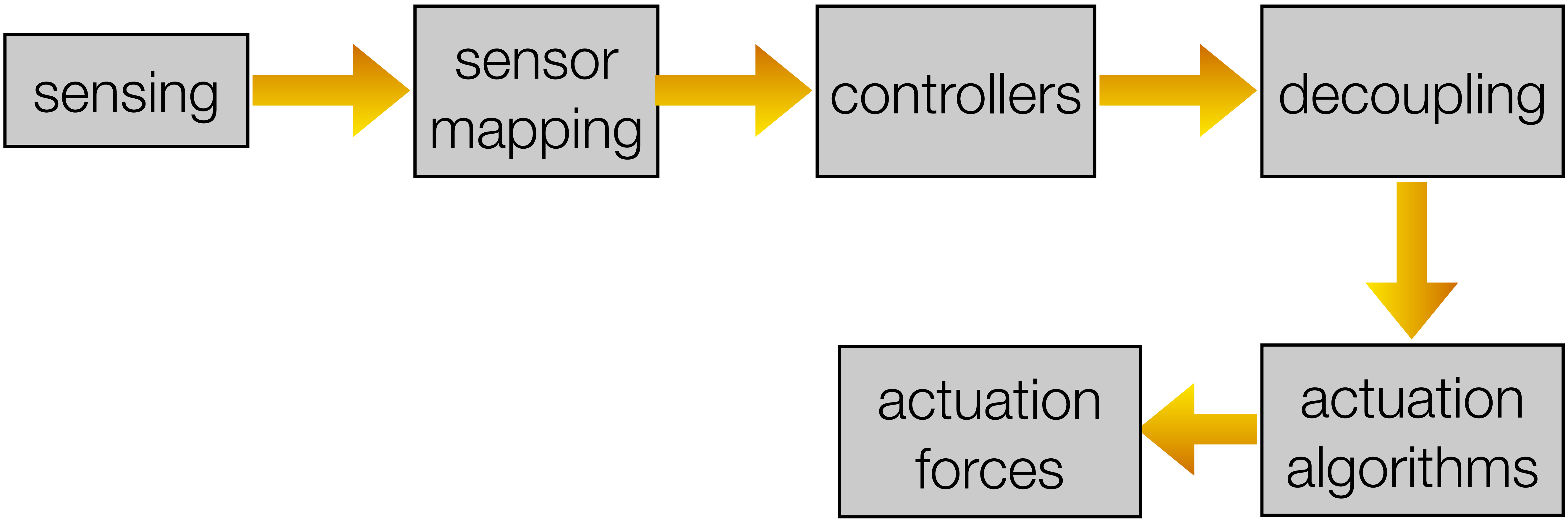

sensing
sensor mapping
controllers
decoupling
actuation algorithms

Control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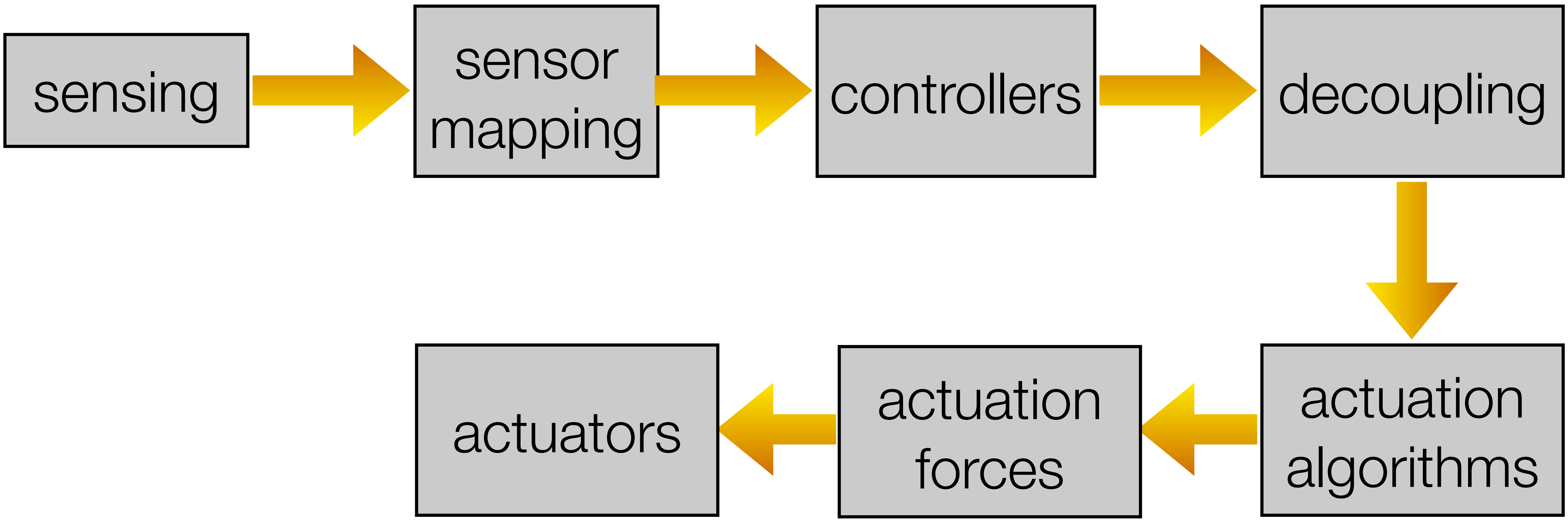
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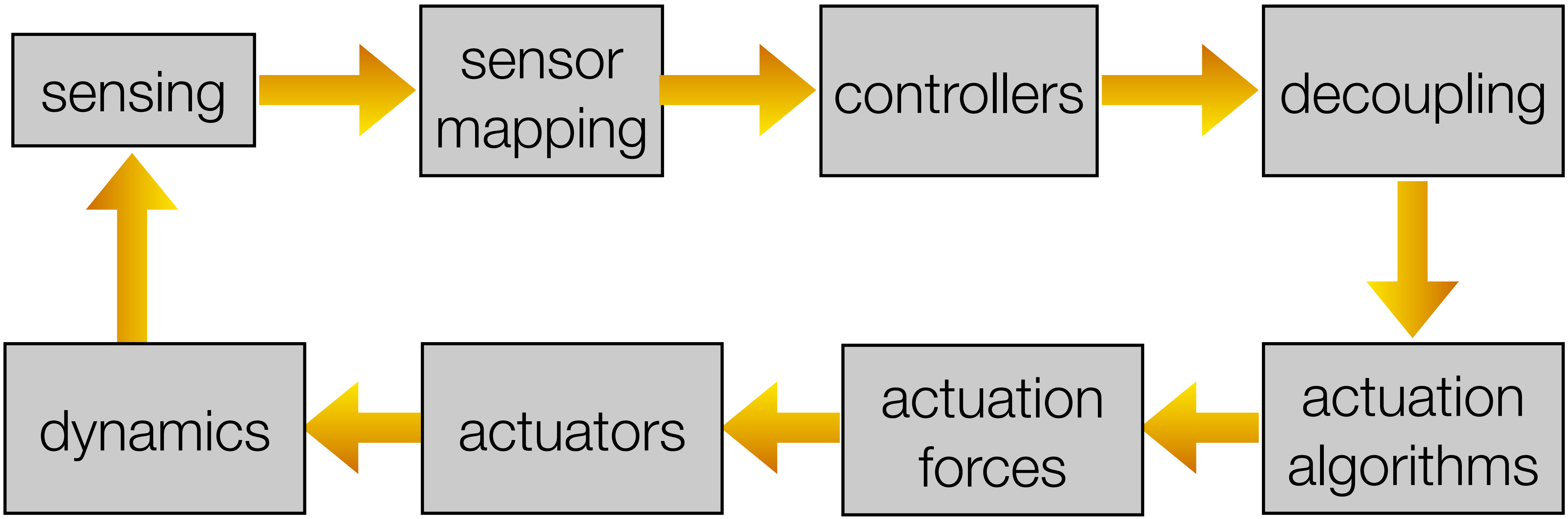

sensing
sensor mapping
controllers
decoupling
actuation algorithms
actuation forces
actuators
dynamics

Science Goals

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- Obtain the best geodesic motion possible
  - quietest differential acceleration of the two TMs
    - 3×10^{-14} m s^{-2} at 1 mHz
      - pm accuracy position measurement of TM-SC, TM-TM
  - commissioning by changing system parameters
    - determine best configuration by experiments

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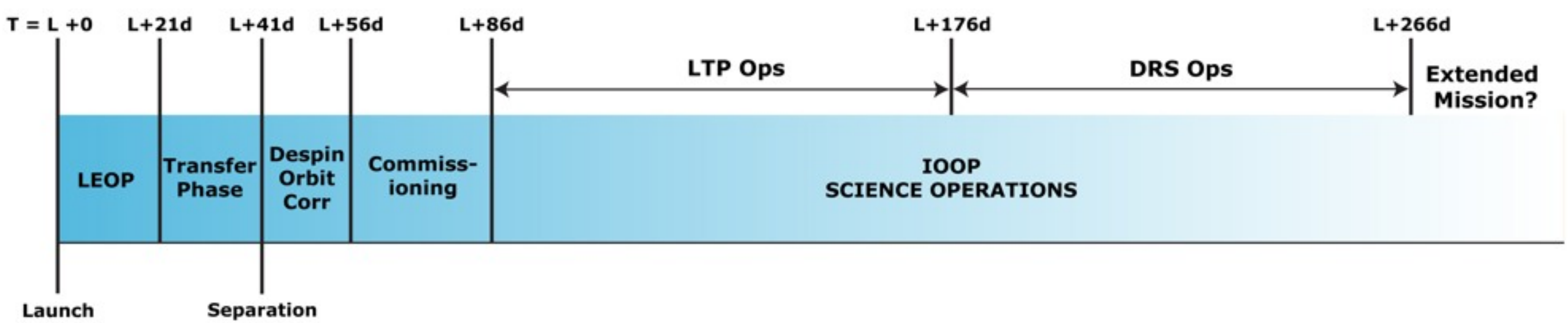
- Develop a noise model of the system
  - allows the projection of the performance of technologies to LISA

Mission Operations

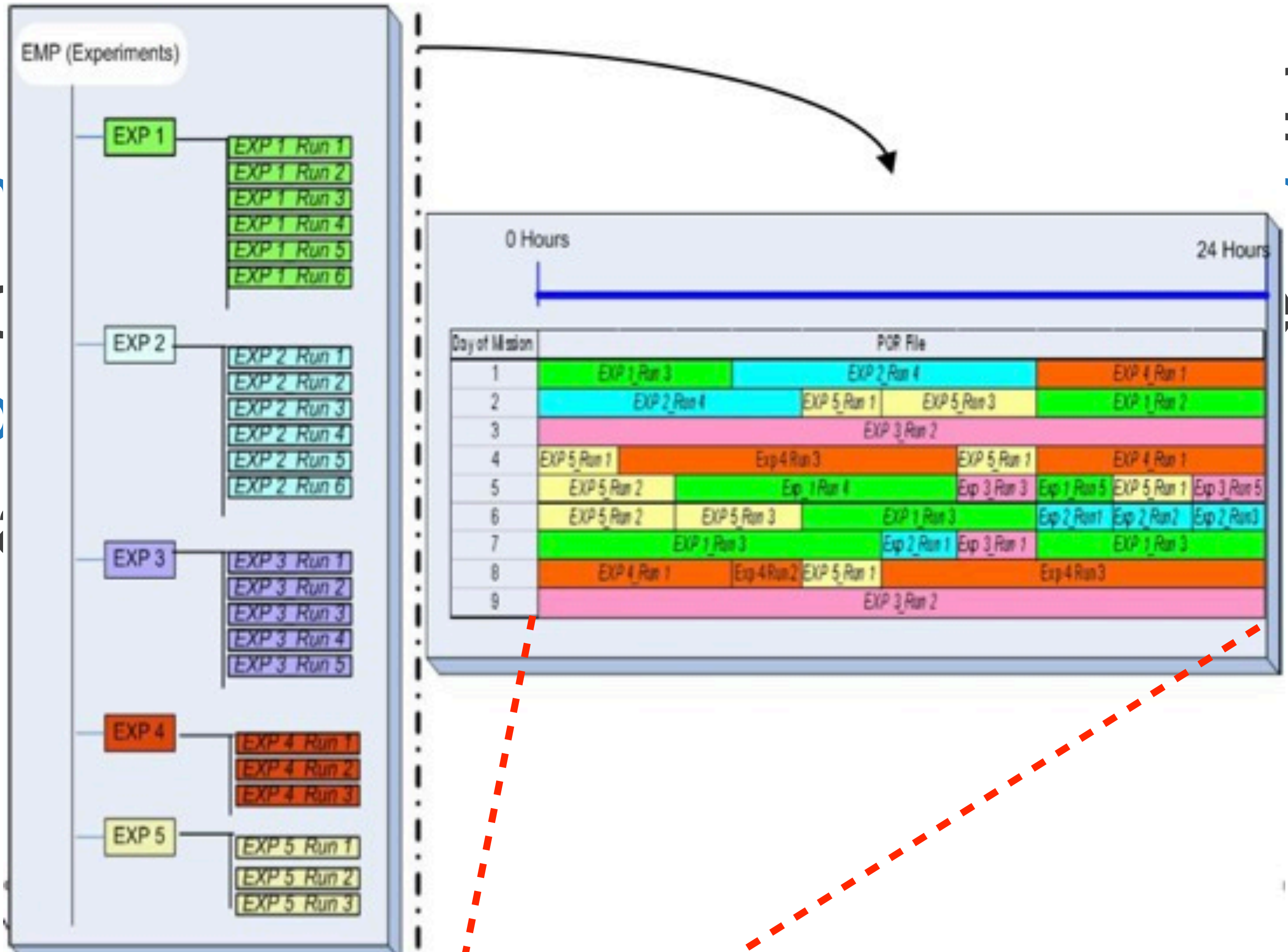
- We have 90 days to achieve the goals
  - characterise and optimise the system
- All days are filled with pre-planned experiments
  - some flexibility is built-in
- Data analysis of the experiments will be done in real-time

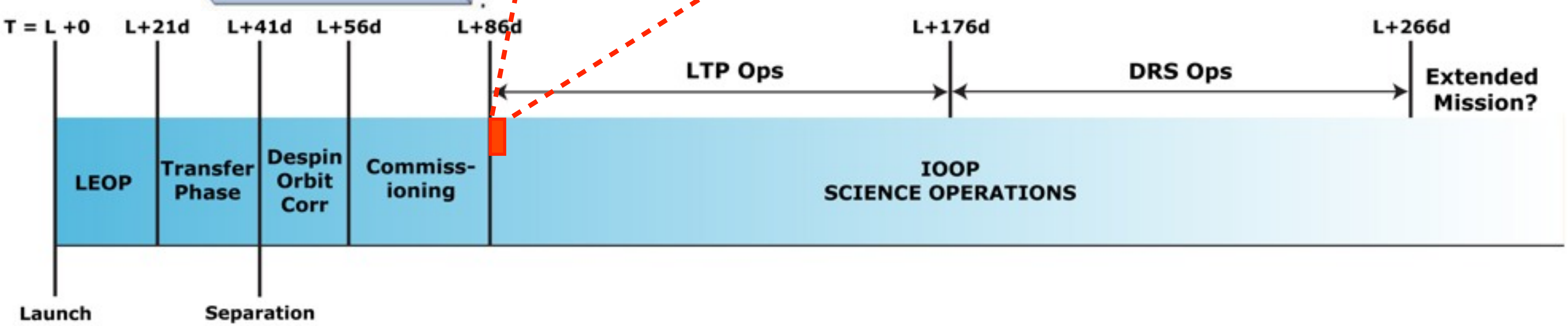


Tuesday, May 24, 2011

Mission Operations

- We … goals
  - ch … n
- All c … ed experiments
  - sc
- Data … will be done in real





Experiments

- Technical studies are broken down in to investigations
- These investigations are then packed in to the time-line

Measurement of Parasitic Voltages
Measurement of differential acceleration noise on LISA Pathfinder
Measurement of cross-talk between the y-axis and the x-axis on the LTP
Measurement of LTP dynamical coefficients by system identification
Analysis of Data from the Radiation Monitor on LISA Pathfinder
Thermal experiments on board the LTP
Magnetic experiments on board the LTP
OPD noise investigations for LTP
Laser frequency noise characterisation for LTP
Laser Amplitude Noise Characterisation for LTP
The Drift Mode for LISA Pathfinder

System identification

System identification

- Many optimisation steps require measurement of physical parameters of the system

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  - e.g. stiffness of TM-SC coupling, IFO X-talk

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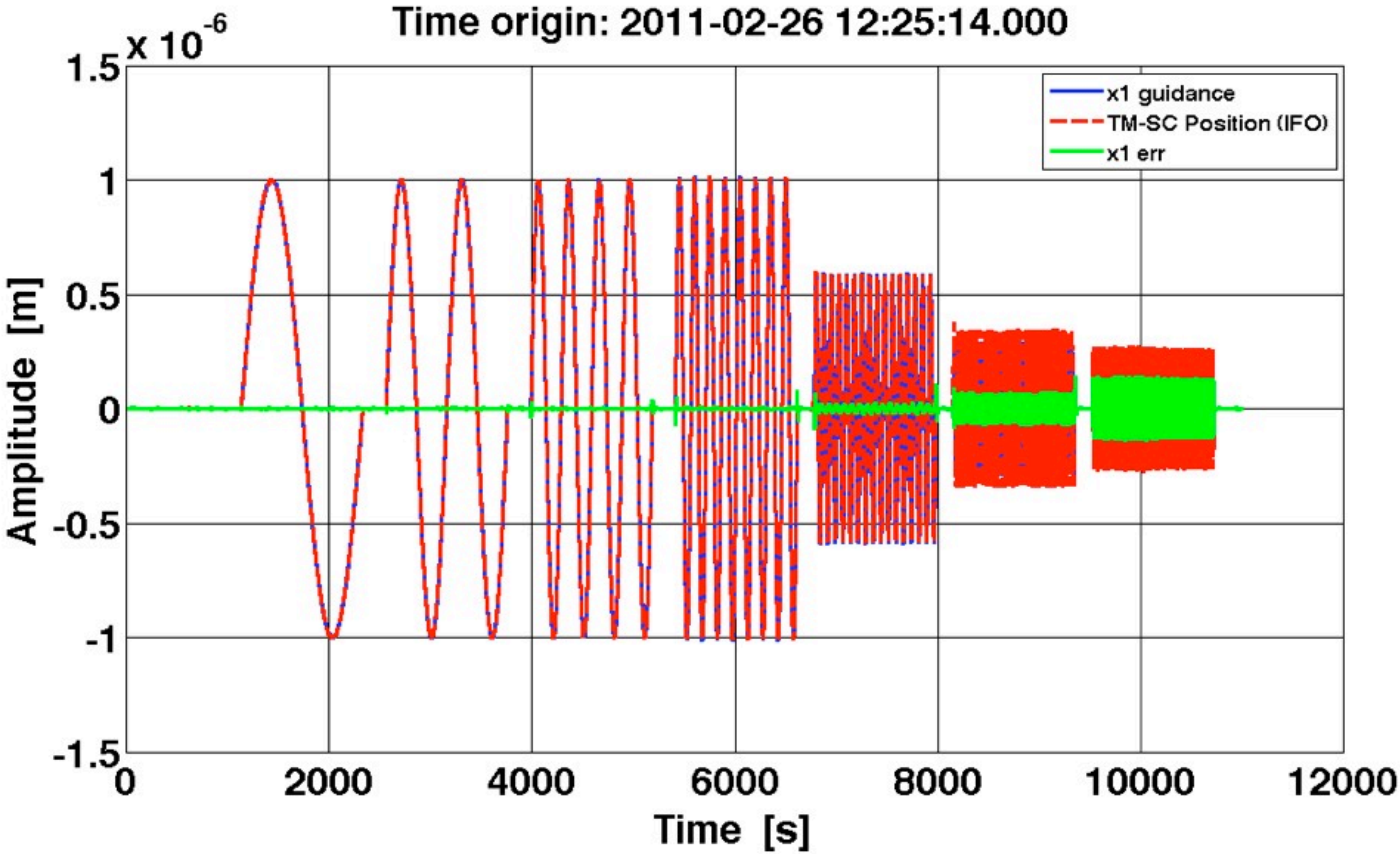
- Dedicated experiments aim at determining small sets of these physical parameters
  - e.g. stiffness of TM-SC coupling, IFO X-talk
- Example: *x*-axis system identification
  - injecting signals in *x*-axis control loops we can measure:
    - stiffness of the two test-masses, actuator gains, IFO X-talk, loop delays

Guidance signals on drag-free

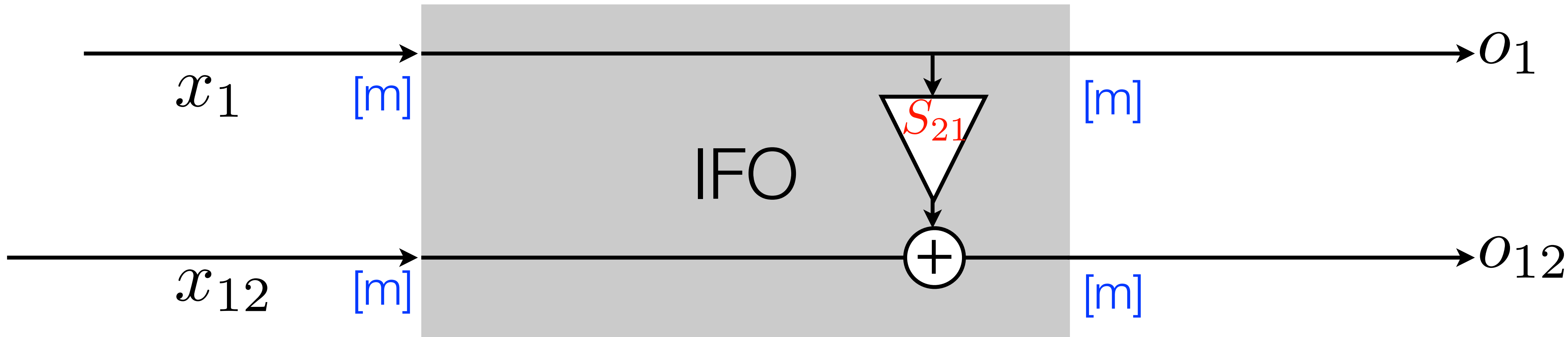


Parameter estimation

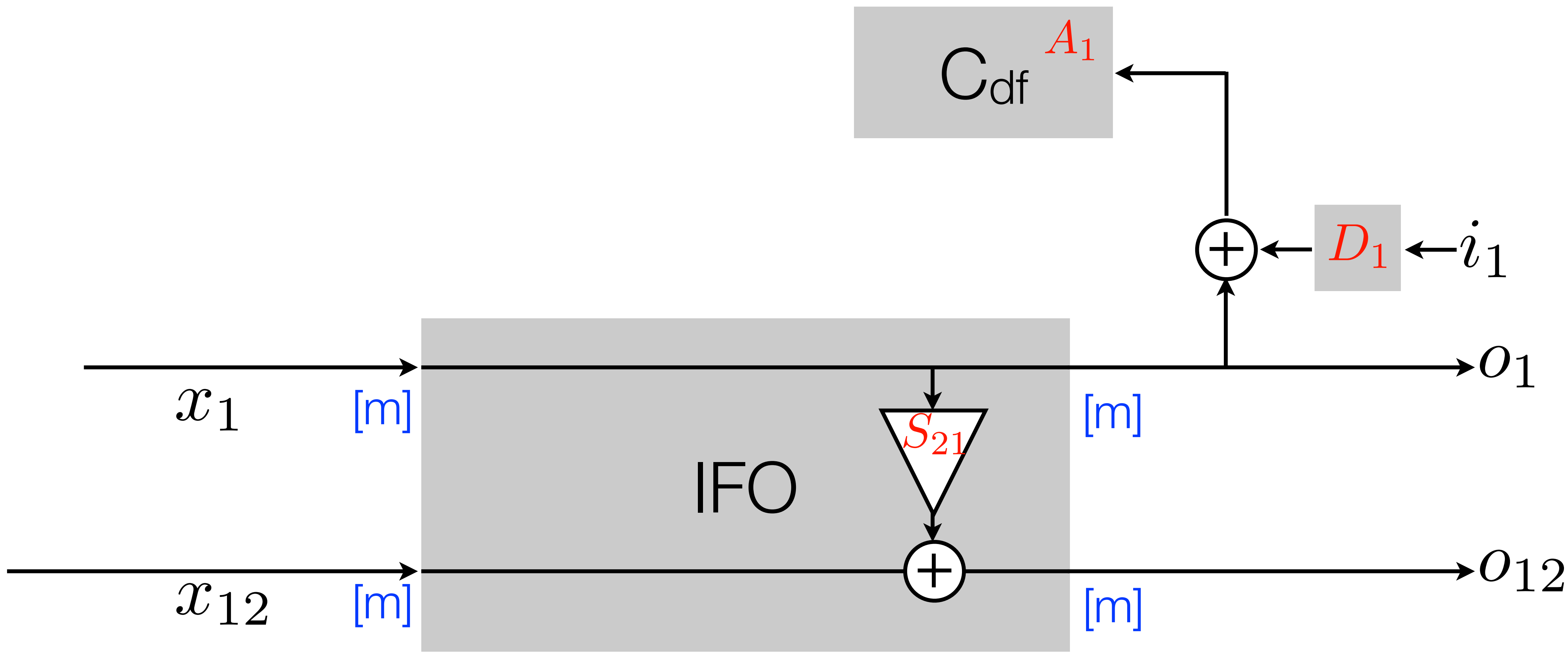
- We have explored three methods:
  - linear least squares
  - non-linear least squares
  - Markov Chain Monte Carlo
- All methods work with multiple inputs, multiple outputs
- All methods require a parametric model of the system

Model

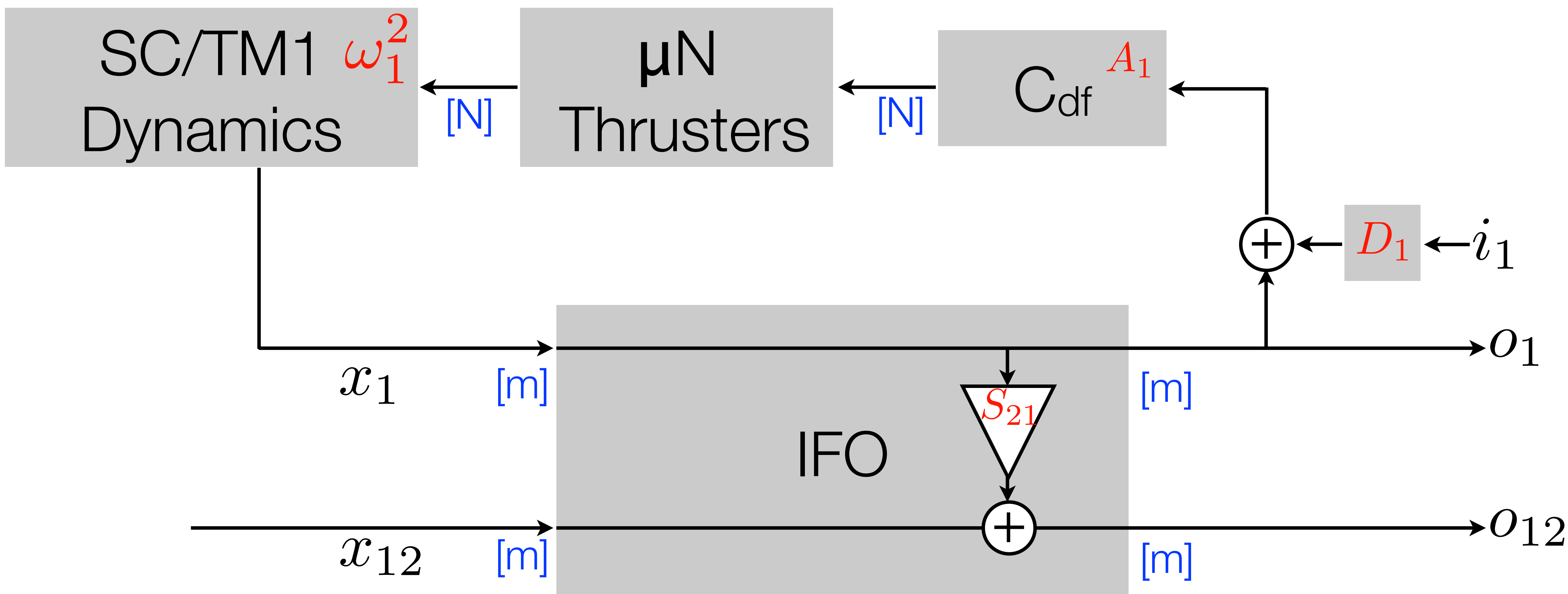
Model



Model

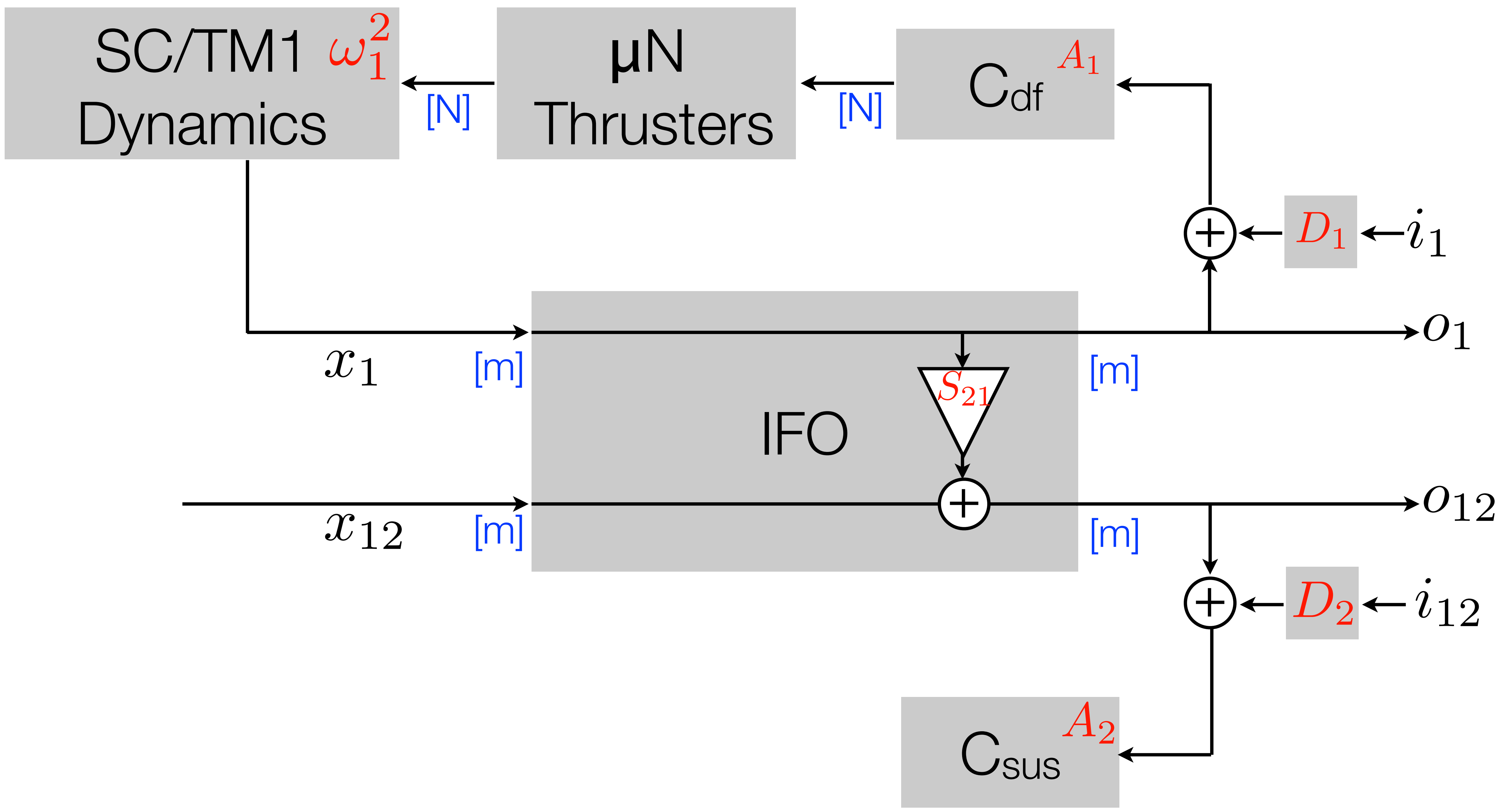


Model



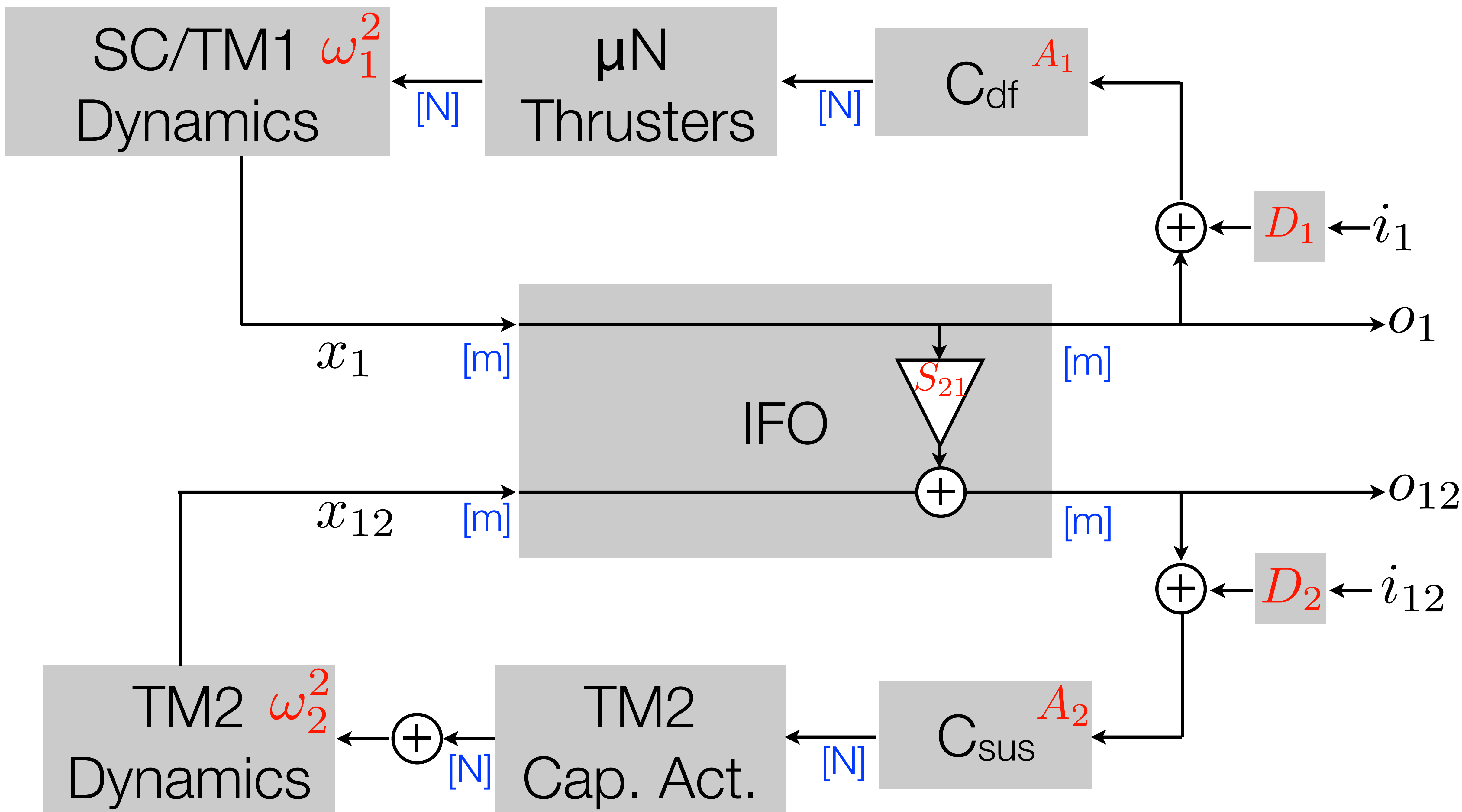
SC/TM1 ω_1^2
Dynamics
[N]
µN
Thrusters
[N]
C_{df} A_1
D_1
i_1
o_1
x_1
[m]
[m]
IFO
S_{21}
x_{12}
[m]
[m]
o_{12}

Model



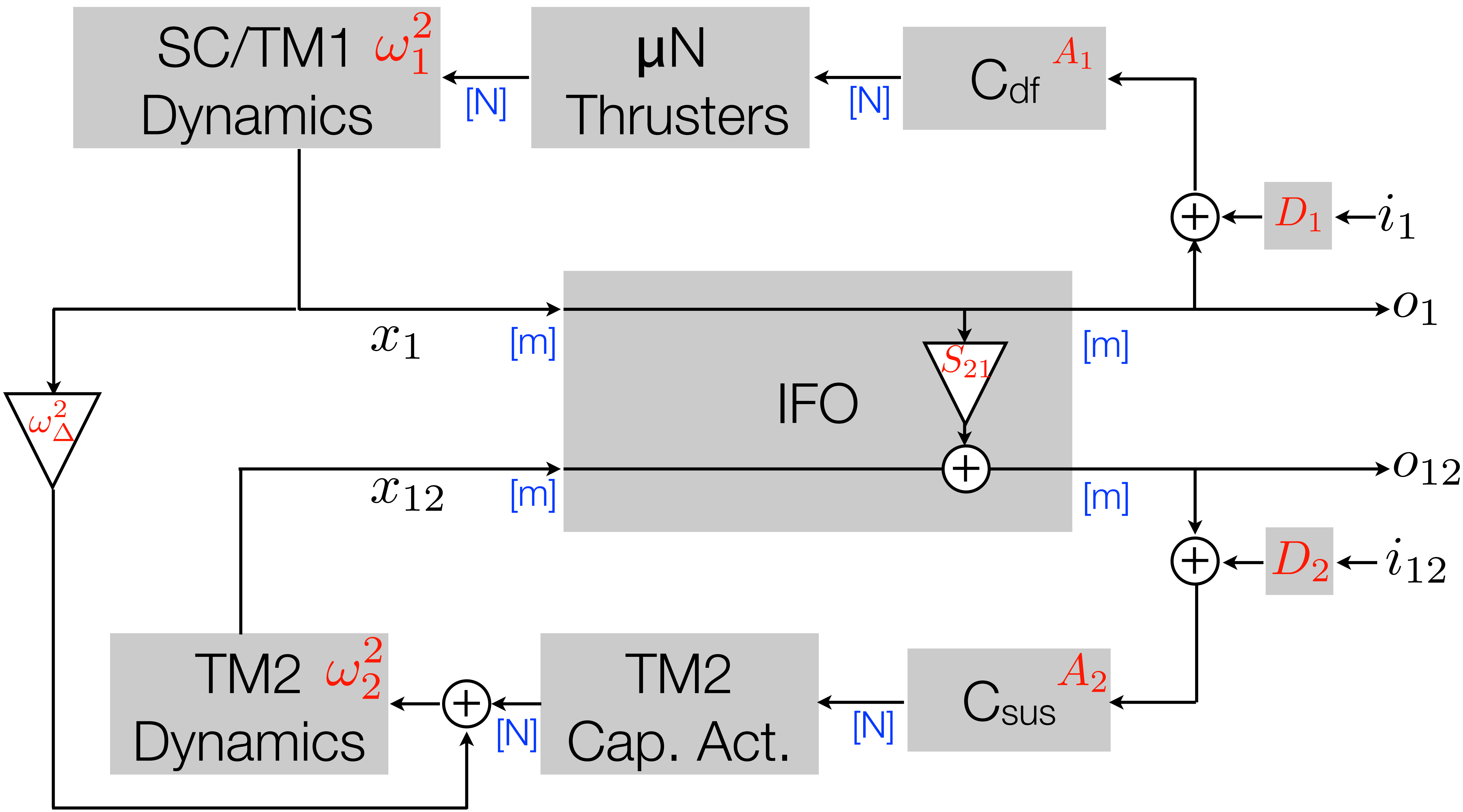
SC/TM1 ω_1^2
Dynamics
[N]
µN
Thrusters
[N]
C_{df} A_1
D_1
i_1
o_1
x_1
[m]
[m]
IFO
S_{21}
x_{12}
[m]
[m]
o_{12}
D_2
i_{12}
C_{sus} A_2

Model



SC/TM1 ω_1^2
Dynamics
[N]
μN
Thrusters
[N]
C_{df} A_1
D_1
i_1
x_1
[m]
IFO
S_{21}
[m]
o_1
x_{12}
[m]
[m]
o_{12}
D_2
i_{12}
TM2 ω_2^2
Dynamics
[N]
TM2
Cap. Act.
[N]
C_{sus} A_2

Model

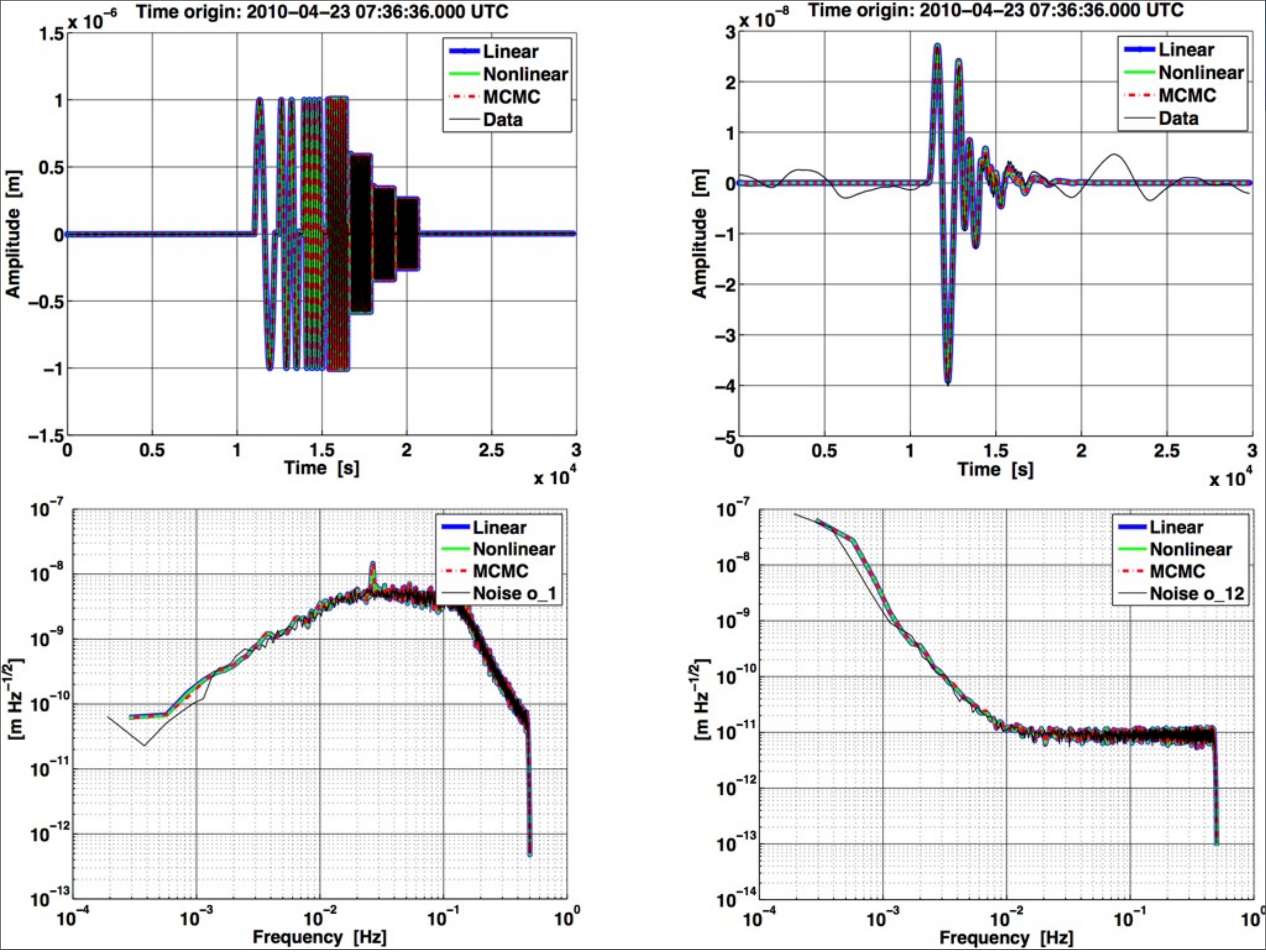


SC/TM1 ω_1^2
Dynamics
µN
Thrusters
C_{df} A_1
[N]
[N]
D_1
i_1
x_1
[m]
IFO
S_{21}
[m]
o_1
ω_Δ^2
x_{12}
[m]
[m]
o_{12}
D_2
i_{12}
TM2 ω_2^2
Dynamics
TM2
Cap. Act.
C_{sus} A_2
[N]
[N]

Results using mission simulator

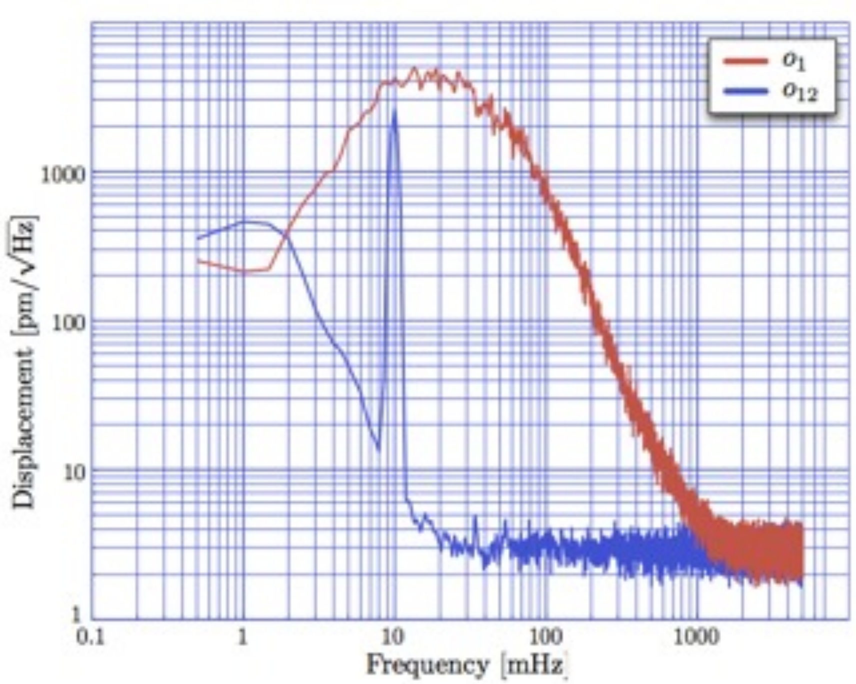
- We can simulate experiments using the mission simulator
  - 3D, non-linear, time-domain simulation
- We can recover the parameters with high precision
  - very dependent on having a good model

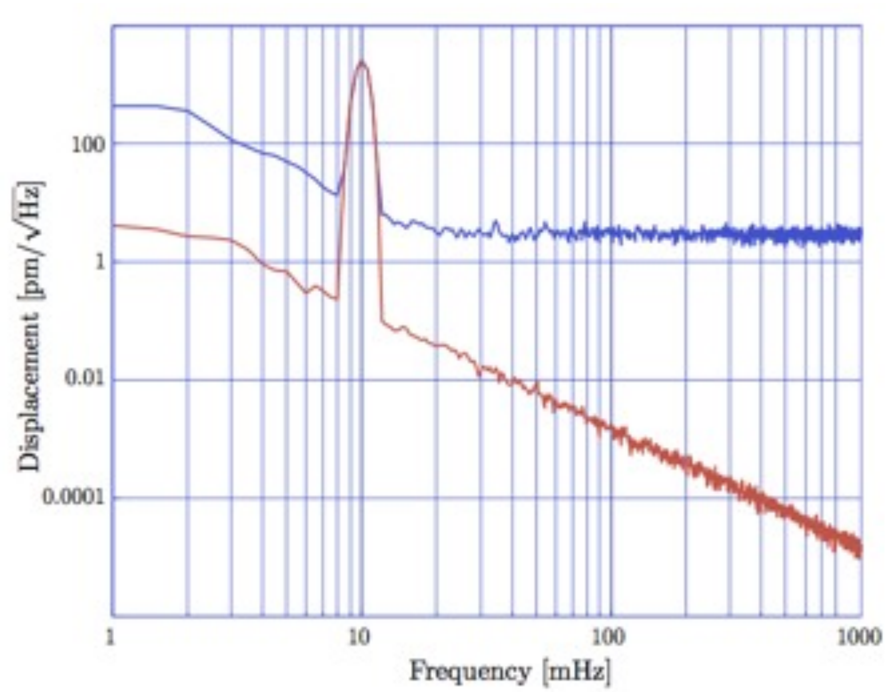
Parameter	**Linear** $\hat{x} \pm \sigma$	**Non-linear** $\hat{x} \pm \sigma \, (\sigma/\sigma_{CR})$	**MCMC** $\hat{x} \pm \sigma \, (\sigma/\sigma_{CR})$
A1	1.0699 ± 0.0005	1.0705 ± 0.0006	1.0701 ± 0.0003
A2	0.99998 ± 0.00003	0.99998 ± 0.00003	0.99997 ± 0.00002
S21	$(1.2 \pm 0.4) \times 10^{-6}$	$(1.2 \pm 0.4) \times 10^{-6}$	$(2.0 \pm 0.2) \times 10^{-6}$
del1	-0.1982 ± 0.0005	-0.1985 ± 0.0005	-0.2020 ± 0.0001
del2	-0.199 ± 0.001	-0.199 ± 0.001	-0.1995 ± 0.0008
ω_2^1	$(-1.319 \pm 0.002) \times 10^{-6}$	$(-1.319 \pm 0.002) \times 10^{-6}$	$(-1.320 \pm 0.001) \times 10^{-6}$
$\omega_2^2 - \omega_1^2$	$(-7.160 \pm 0.006) \times 10^{-7}$	$(-7.160 \pm 0.006) \times 10^{-7}$	$(-7.148 \pm 0.006) \times 10^{-7}$

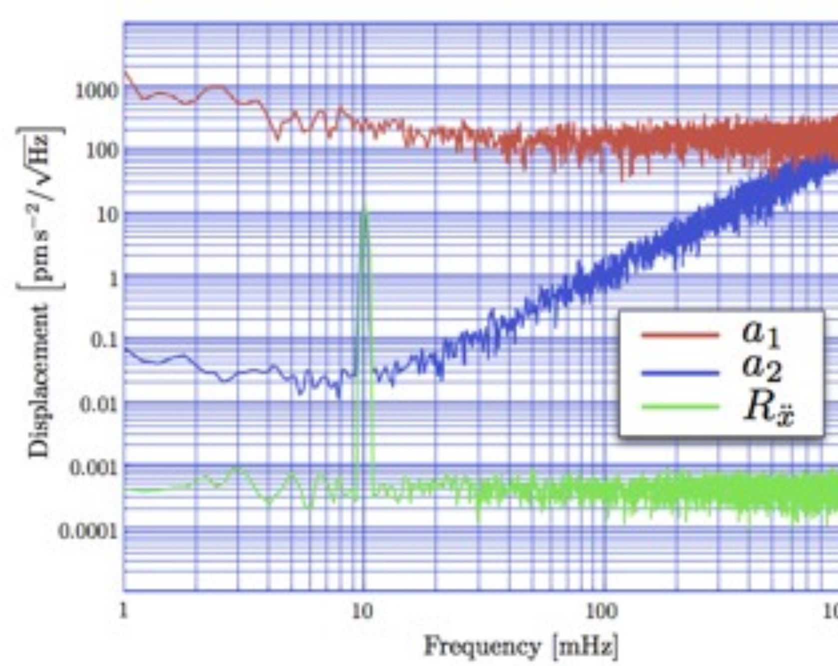

Time origin: 2010–04–23 07:36:36.000 UTC
Linear
Nonlinear
MCMC
Data
Amplitude [m]
Time [s]
Time origin: 2010–04–23 07:36:36.000 UTC
Linear
Nonlinear
MCMC
Data
Amplitude [m]
Time [s]
Linear
Nonlinear
MCMC
Noise o_1
[m Hz^−1/2]
Frequency [Hz]
Linear
Nonlinear
MCMC
Noise o_12
[m Hz^−1/2]
Frequency [Hz]

Laser amplitude noise

- If the laser stabilisation fails, the force noise on the TM from fluctuations in radiation pressure can become significant
- Experiment:
  - modulate laser power at 1mHz
  - measure coupling of RIN to TM displacement
    - depends on power, TM reflectivity, photodiode calibration



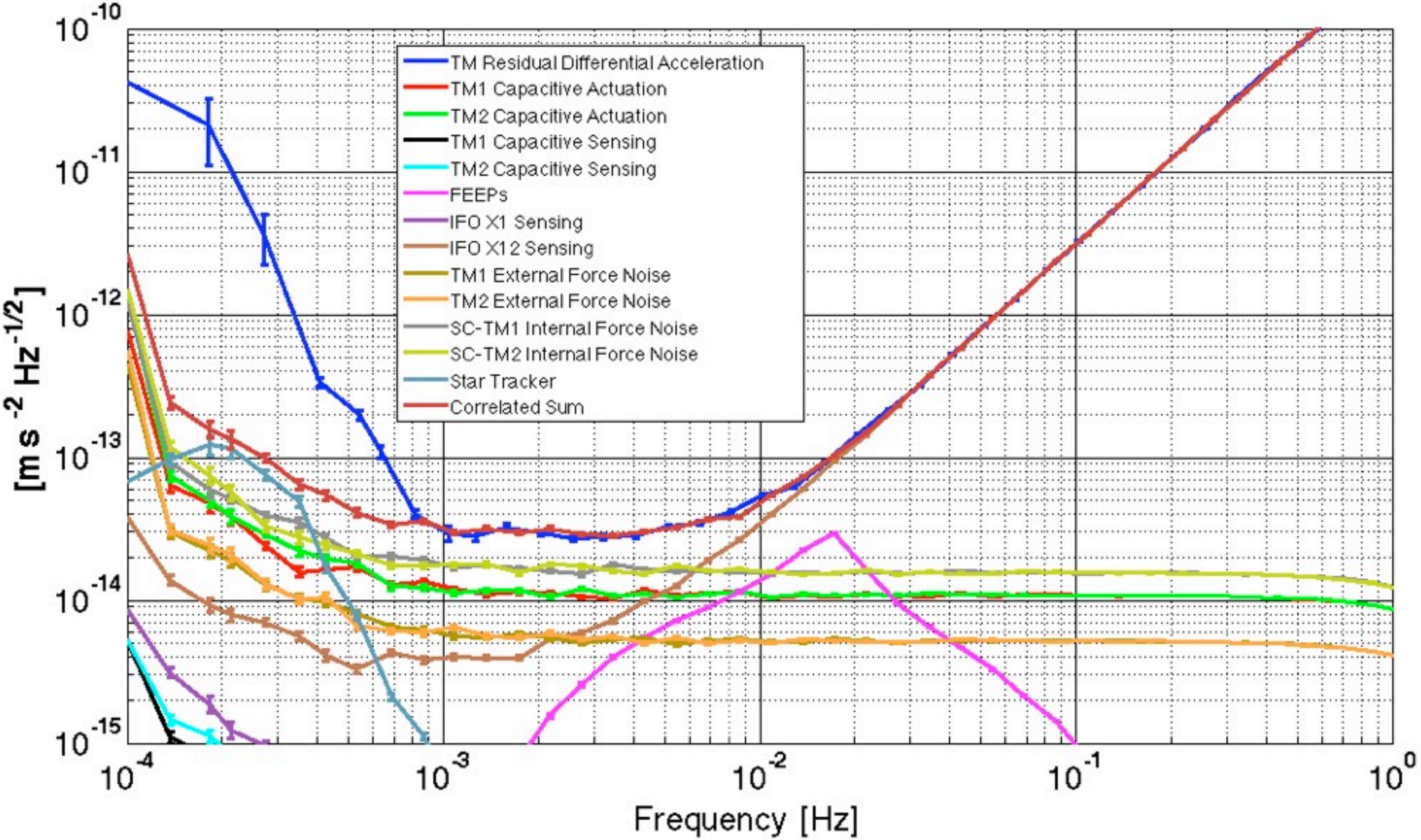




Noise budget

- Various noise contributions can be directly measured
- Some noise sources can be measured
- Some noise couplings must be modelled
  - using estimates of physical parameters together with a system model
- Some noise contributions must be estimated/ modelled from design

Noise budget



Free-flight experiment

Free-flight experiment

- Capacitive actuation will be close to limiting around 1mHz

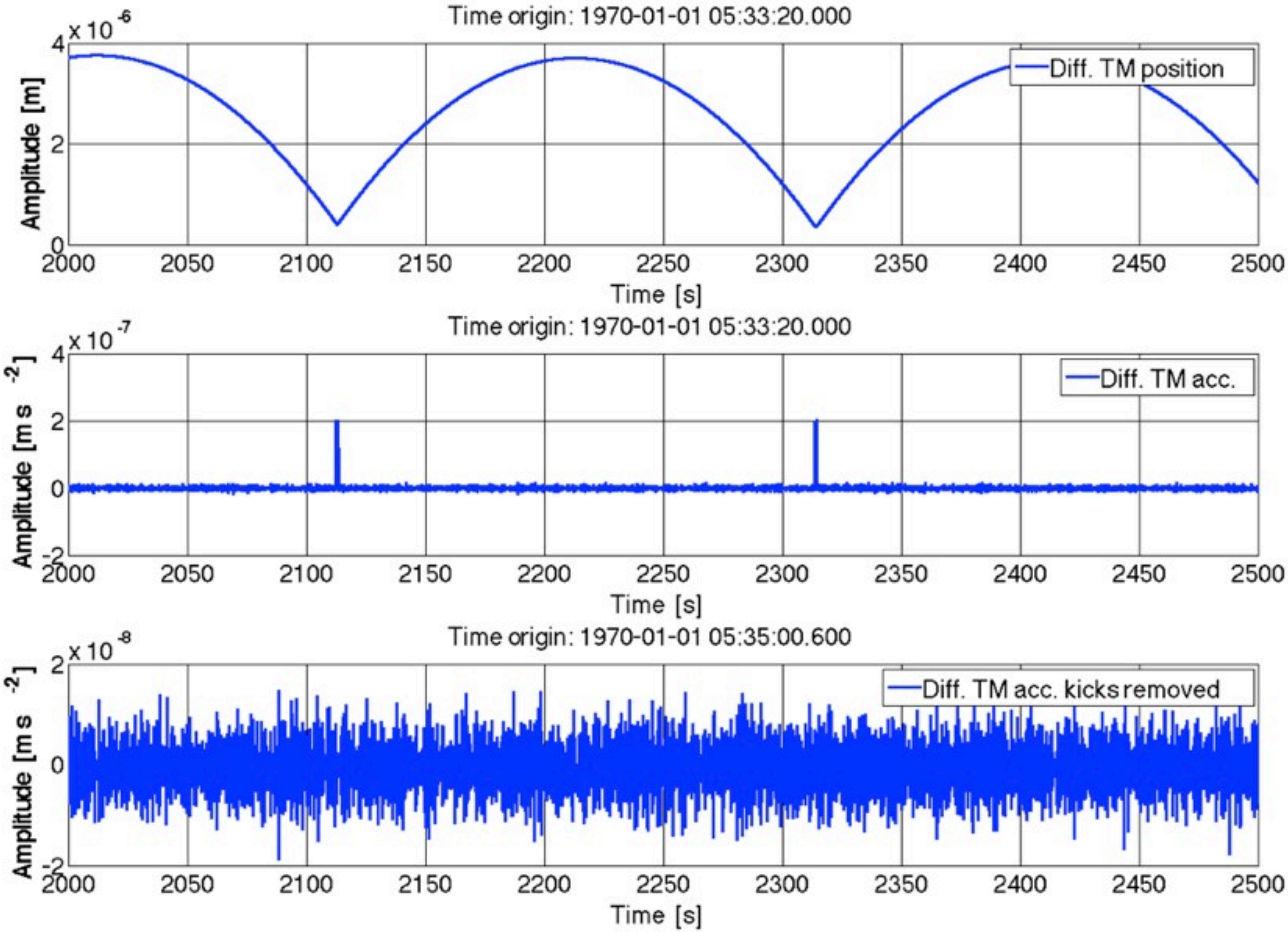
Free-flight experiment

- Capacitive actuation will be close to limiting around 1mHz
- Do an experiment with the actuation off
  - must be short otherwise the TM will drift too far
  - repeat many times

Free-flight experiment

- Capacitive actuation will be close to limiting around 1mHz
- Do an experiment with the actuation off
  - must be short otherwise the TM will drift too far
  - repeat many times
- Experiment:
  - kick test-mass away
  - turn off actuation
  - let the test-mass drift (in parabola)
  - repeat

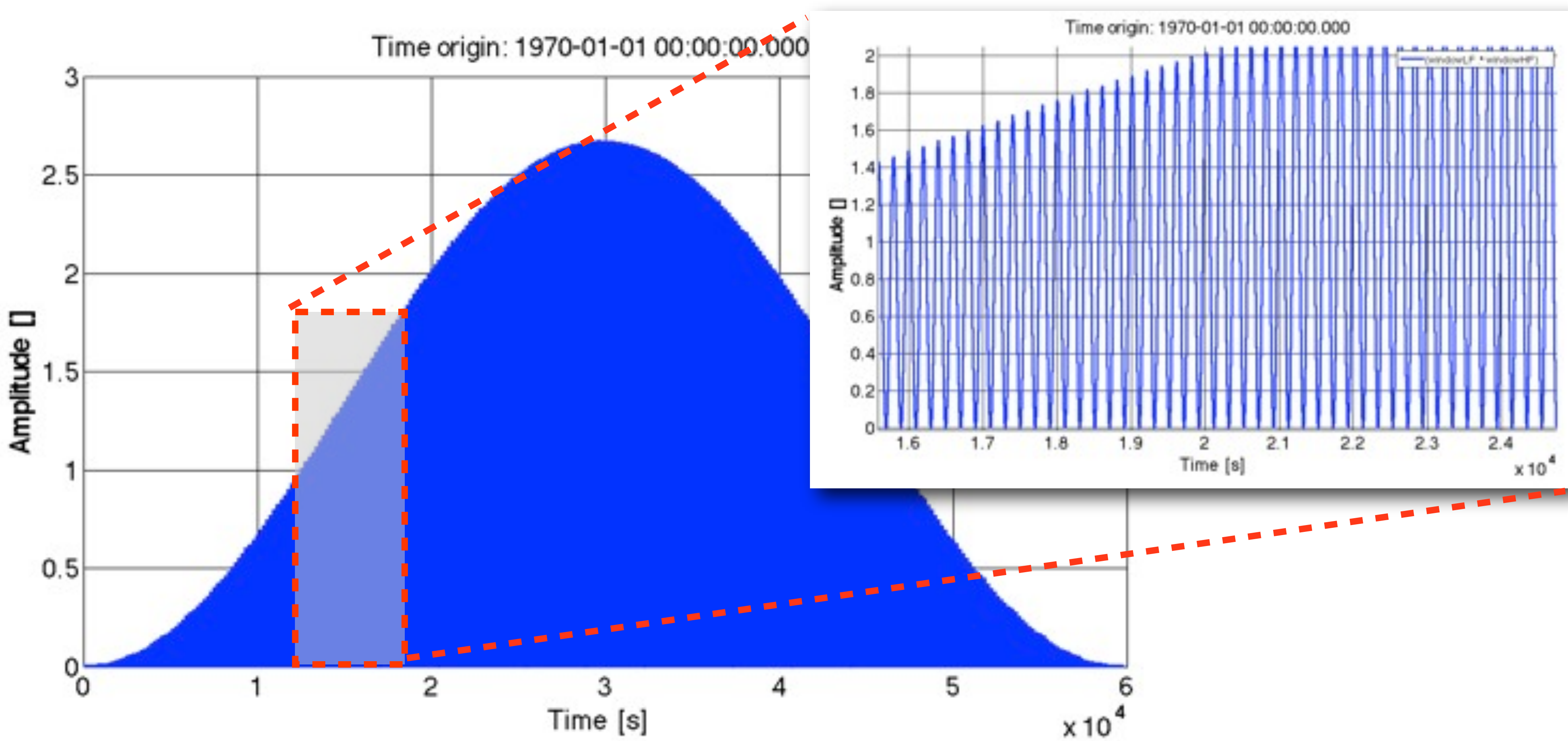
Simulation



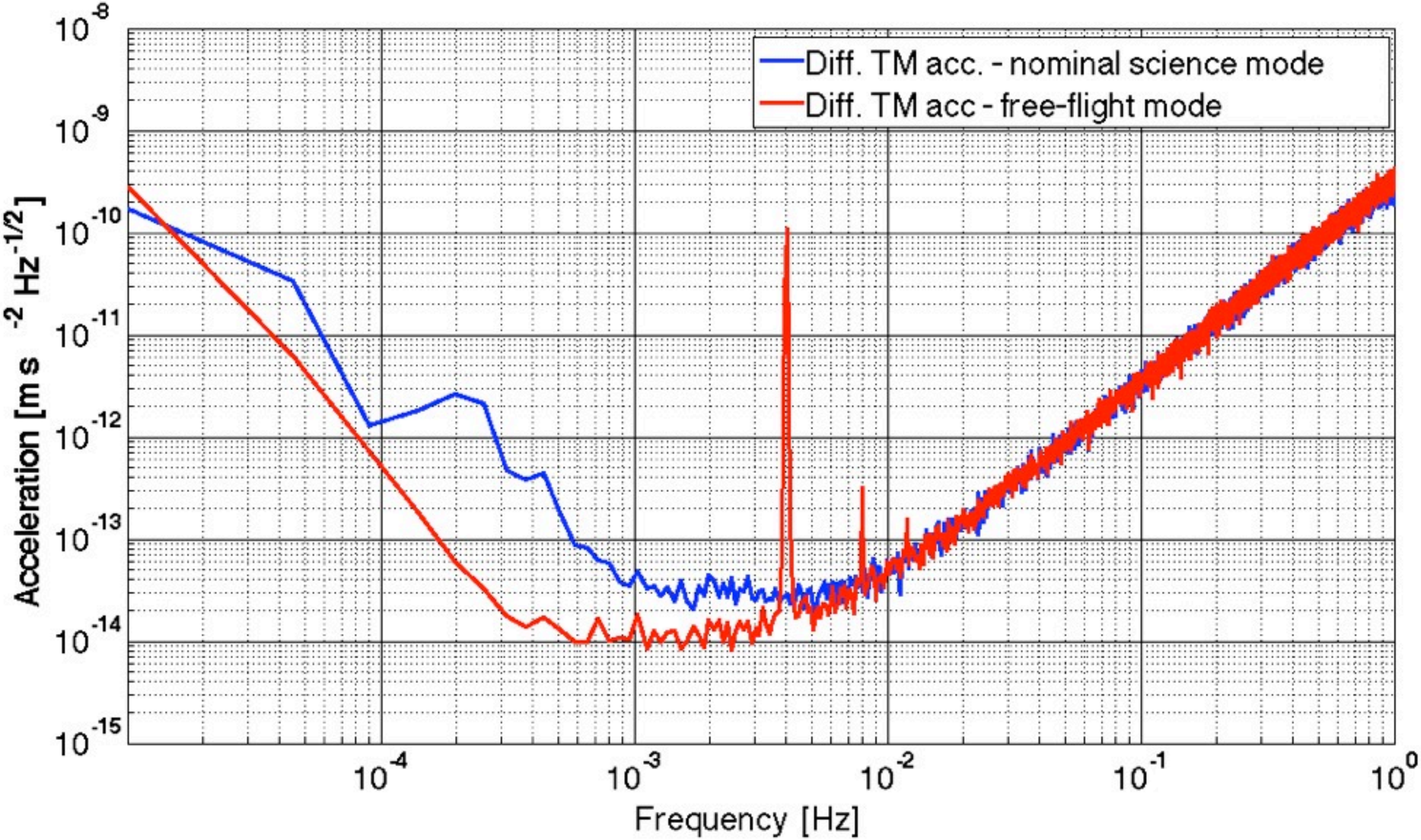
Time origin: 1970-01-01 05:33:20.000
x 10^-6
Amplitude [m]
Diff. TM position
Time [s]
Time origin: 1970-01-01 05:33:20.000
x 10^-7
Amplitude [m s^-2]
Diff. TM acc.
Time [s]
Time origin: 1970-01-01 05:35:00.600
x 10^-8
Amplitude [m s^-2]
Diff. TM acc. kicks removed
Time [s]

Data Analysis

- Need to analyse the multiple short (200s) drift segments to estimate the spectrum at 1mHz
- First approach: window the data, and proceed with normal PSD estimate



PSD Estimate



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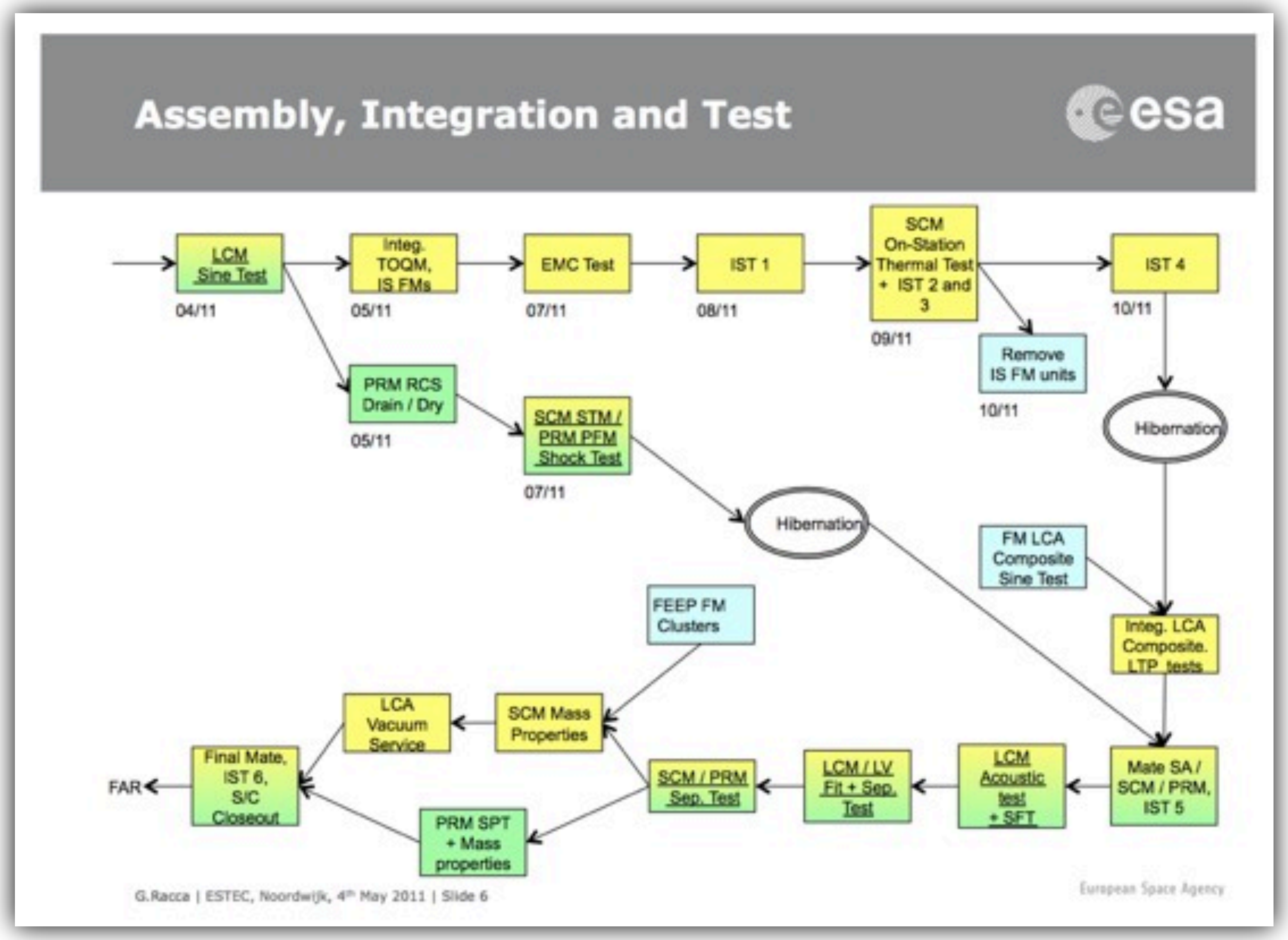
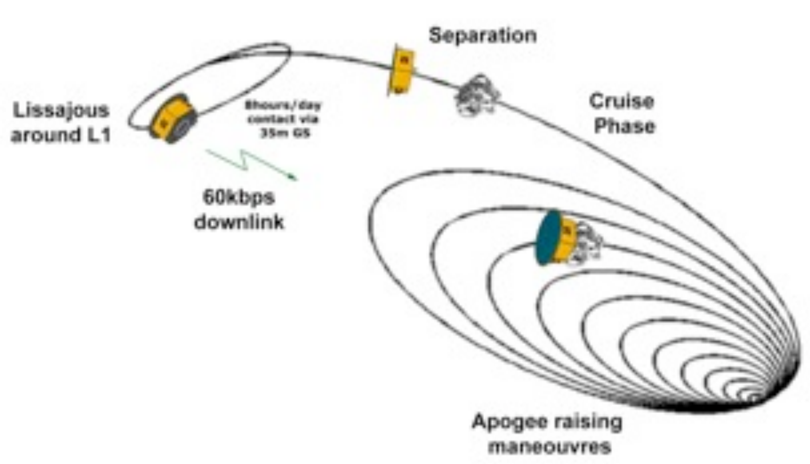
- LPF is well on its way!
  - Most of the hardware is there
    - awaiting thrusters and launch lock
  - Most of the experiments are already defined
    - many are even tested with DA in place
  - We have a clear path to launch
- Launch in 2014





Tuesday, May 24, 2011


Thank you
IABG