The LISA Technology Package on SMART-2

06-02-2003 Maurice te Plate ESA/ESTEC

Contents presentation:

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- Scientific requirements LTP and SMART-2
- Basic Architecture of the LTP
- Optical metrology on the LTP
- Optical design trade-off
- Results pre-investigations phase
- Actual opto-mechanical design LTP
- LTP activities schedule
- Future outlook and conclusions

Industrial organisation

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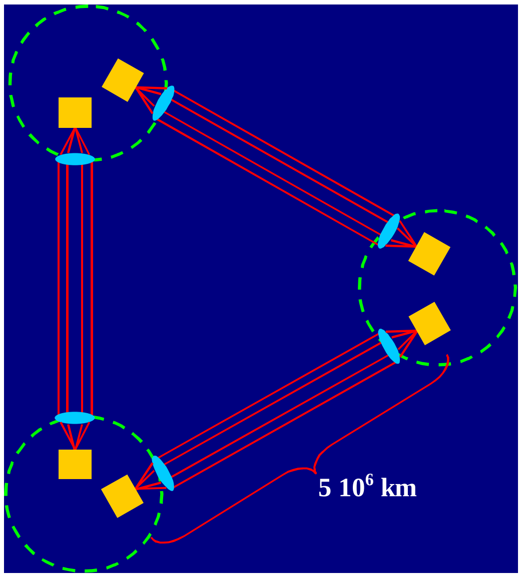
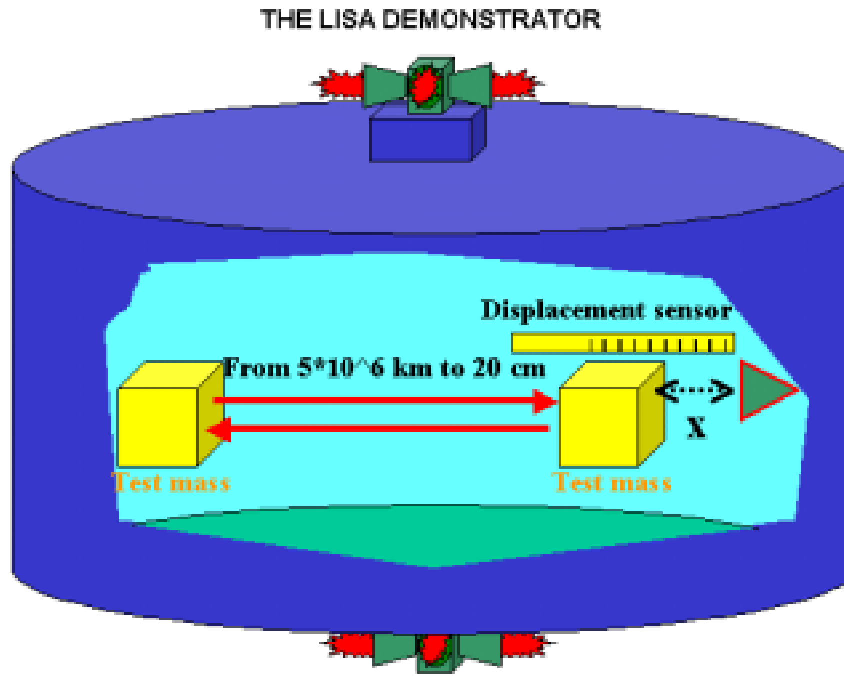
Introduction:





LISA mission:

- Test masses $5 \cdot 10^9$ m separated

SMART-2 mission:

- Demonstrate feasibility of LISA essential technology:
  - Drag-free flying
  - Inertial sensor techniques
  - Ultra high resolution interferometry)
  - Micro Newton thrusters (Feep's)

Scientific requirements SMART-2

- Main goal SMART-2: Demonstrate drag-free flying

LISA mission:

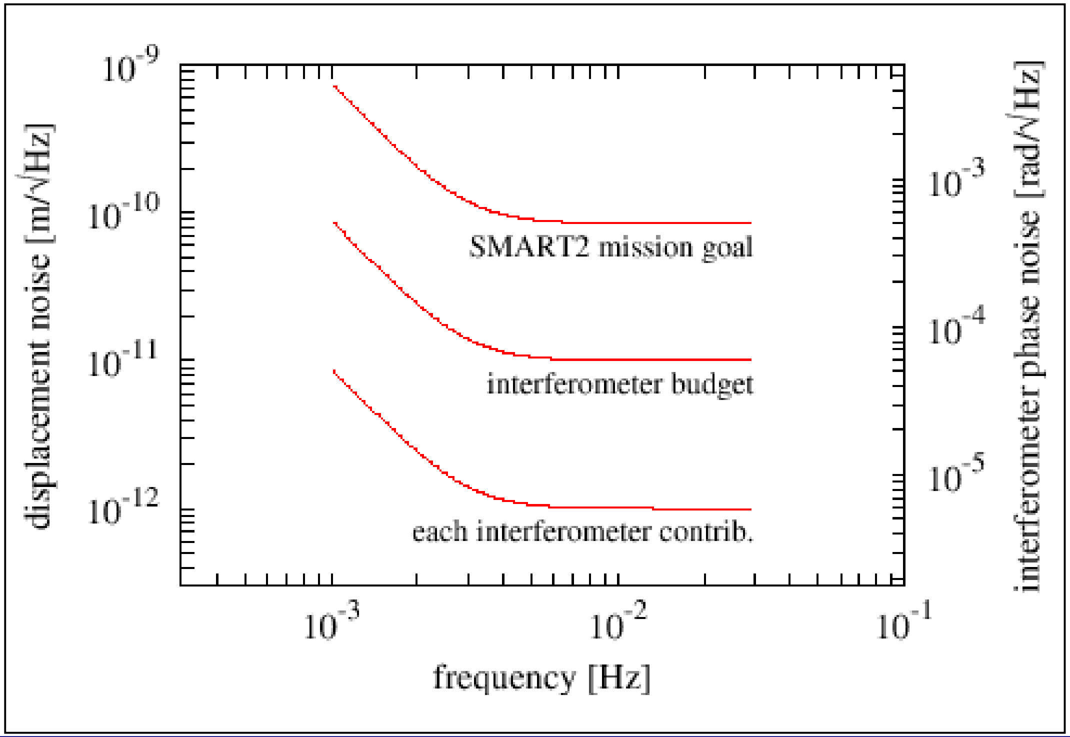
$$S_a^{1/2}(f) \leq 3\times10^{-15}\left[1+\left(\frac{f}{3\text{ mHz}}\right)^2\right]\frac{\text{m}}{\text{s}^2}\frac{1}{\sqrt{\text{Hz}}}$$

For 0.1 mHz … 0.1 Hz

SMART-2 mission:

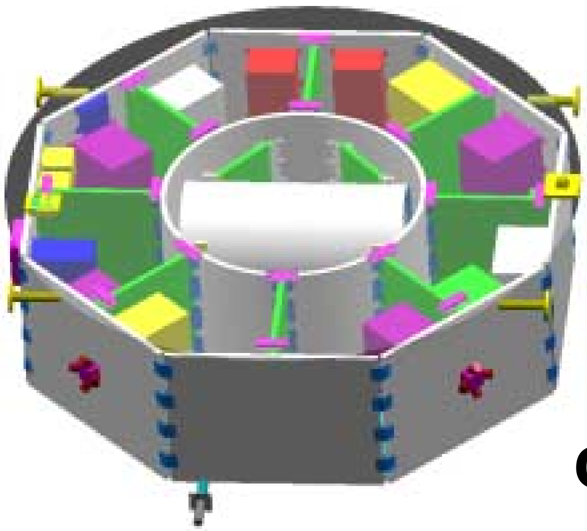
$$S_a^{1/2}(f) \leq 3\times10^{-14}\left[1+\left(\frac{f}{3\text{ mHz}}\right)^2\right]\frac{\text{m}}{\text{s}^2}\frac{1}{\sqrt{\text{Hz}}}$$

For 1 mHz … 30 mHz



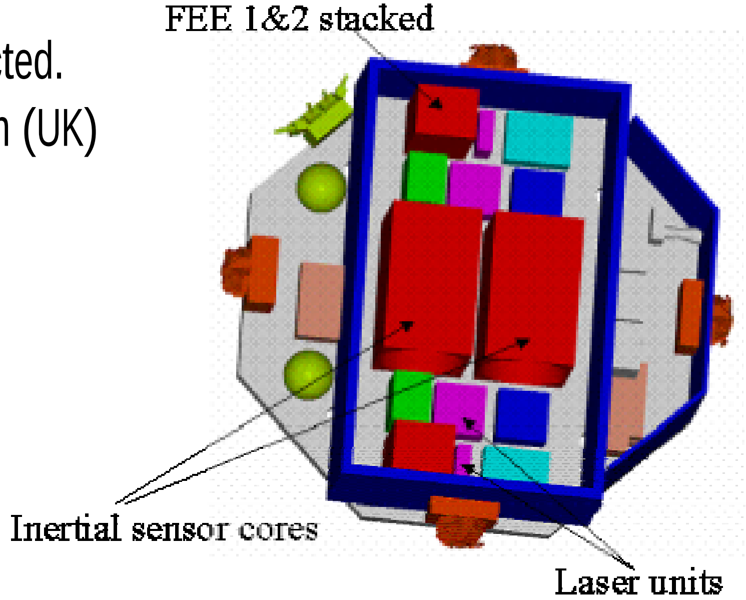
SMART-2

- Small Mission for Advanced Research of Technology
- Mission will fly with LTP and possibly DRS. DTP was rejected.
- Two parallel definition studies. CASA (Spain) and Astrium (UK)



CASA

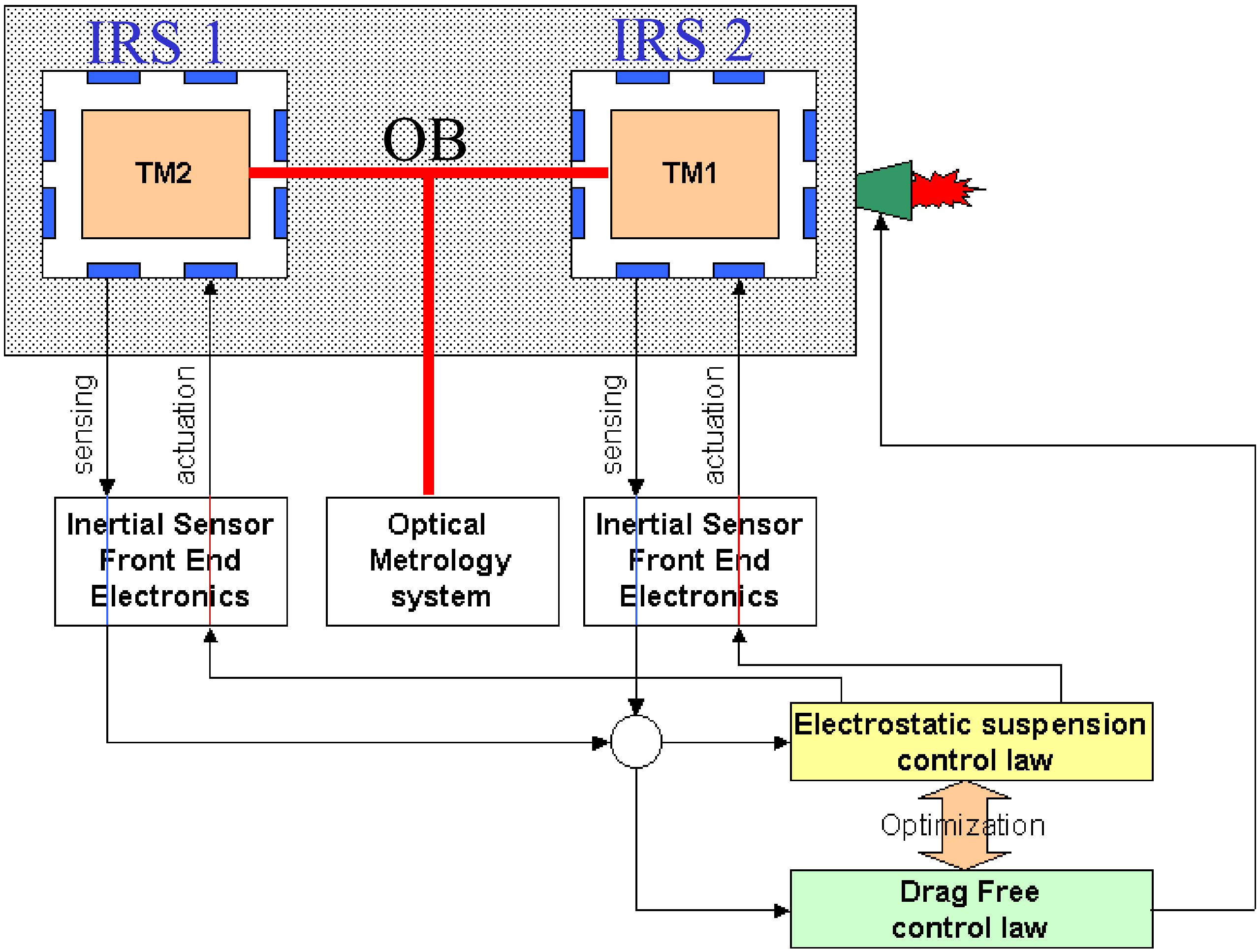
- Central CFRP cylinder concept
- Launch on Ariane 5 as auxiliary payload
- Orbit around L1



Astrium UK

- Mini platform concept
- Launch on Ariane 5 as auxiliary payload
- Orbit around L1

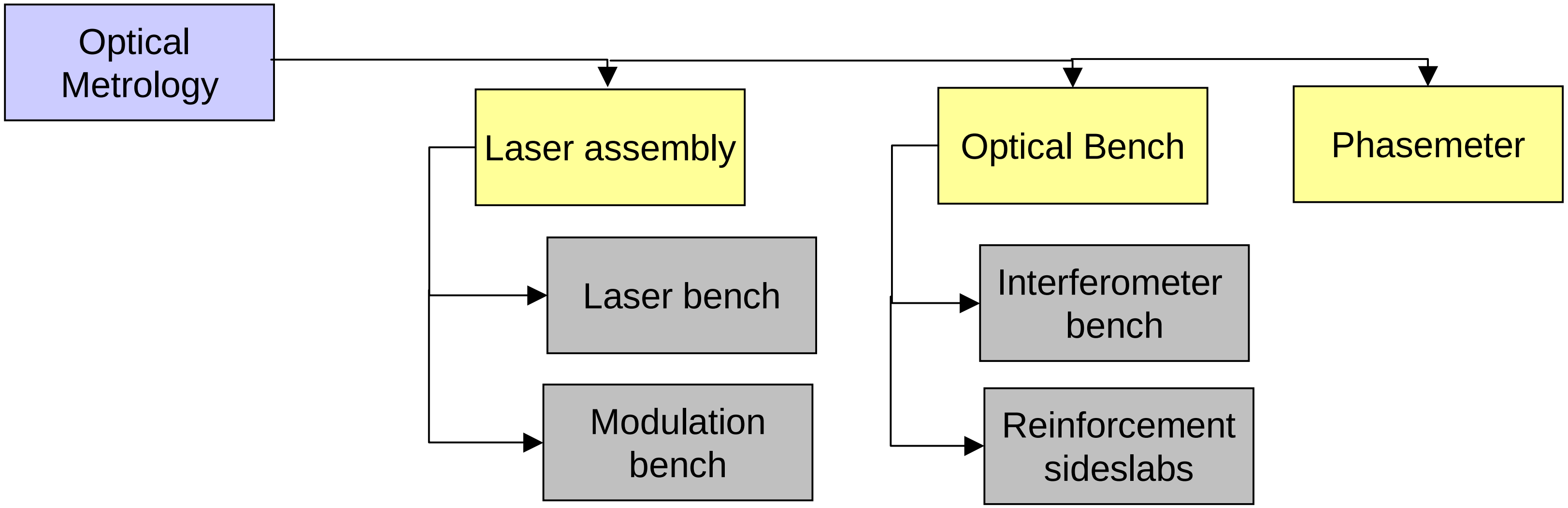
Basic architecture LTP:



Main noise sources:

- Self Gravity effects
- Magnetic Forces
- Electrostatic forces
- Drag-free performance
- Inertial sensor electrostatic characteristics
- Optical path noise (laser frequency and amplitude stability, dn/dT effects, thermal stability and thermal expansion effects)
- S/C induced acceleration effects (sloshing/moving parts etc)

Optical Metrology Subsystems



Main requirements LTP optical bench system

Parameter	Value or Description
measurement principle:	heterodyne interferometer
measurement band width:	1 mHz – 30 mHz
measurement accuracy:	<10 pm/√Hz
measurement range (end mirror displacement):	±100 µm (with phase unwrapping)
temperature range of operation:	+10°C to +30°C
non-operating temperature range:	0°C to +40°C
LTP temperature stability:	Typically 10^{-4}K/√Hz @ 1 mHz – 30 mHz
heterodyne beat frequency:	Around 1 kHz
operational wavelength:	1064 nm
optical bench mass (with interferometer, w/o end mirrors):	< 5 kg
optical bench dimensions (with interfer., w/o end mirrors):	< 200 mm x 200 mm x 50 mm
design loads (axial and lateral):	40 g
mechanical resonance frequency:	>120 Hz
total radiation dose tolerance:	75 krad

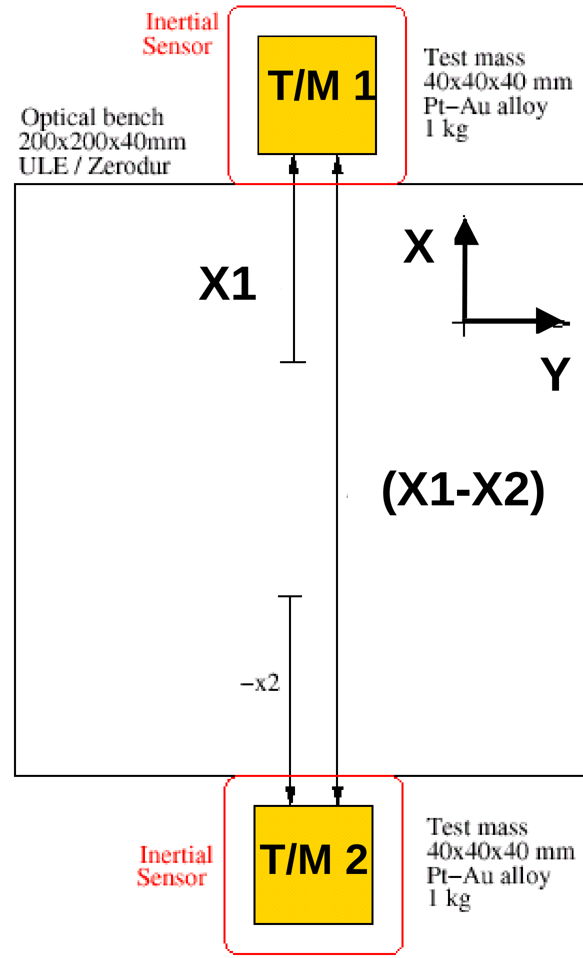
Measurements on LTP optical bench

1) X1-X2: Distance between T/M's

2) X1: Position T/M 1 w.r.t. OB

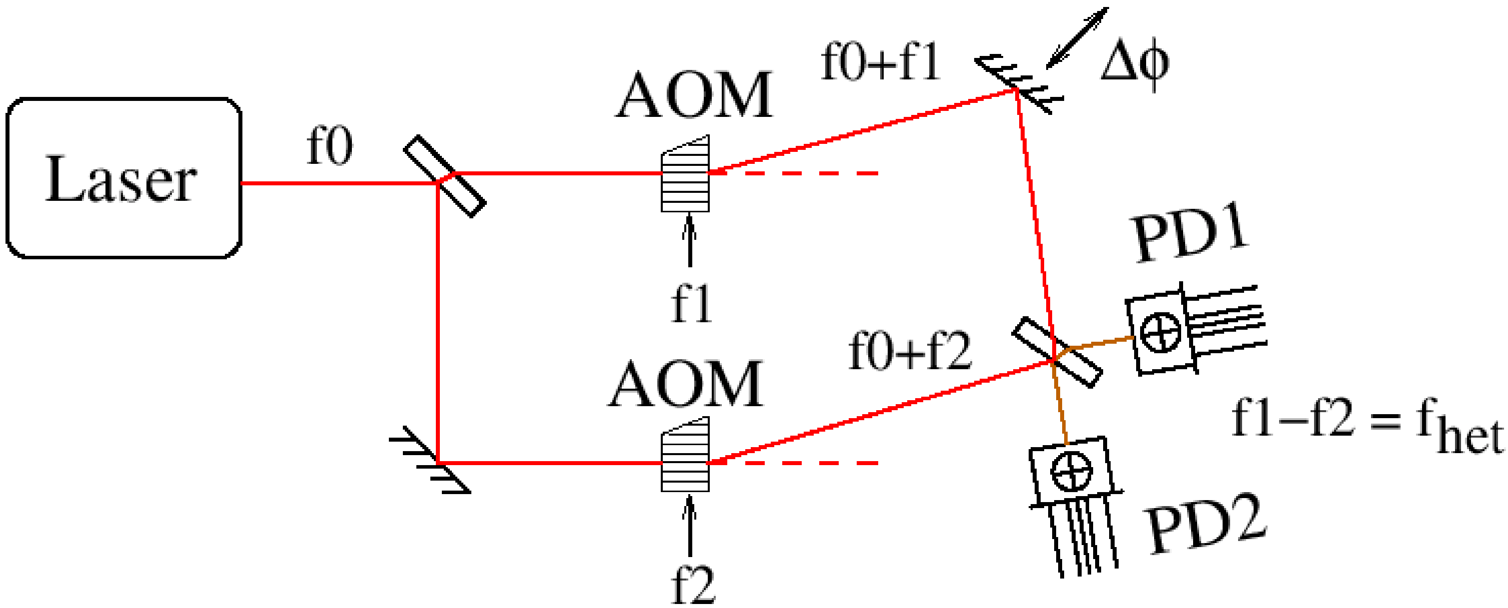
3) Tilt (X1): Tilt T/M 1 (Y and Z-axes)

4) Tilt (X1-X2): Differential Tilt T/M 1 and T/M 2



Remark: No absolute length will be measured, only fluctuations within the measurement frequency band

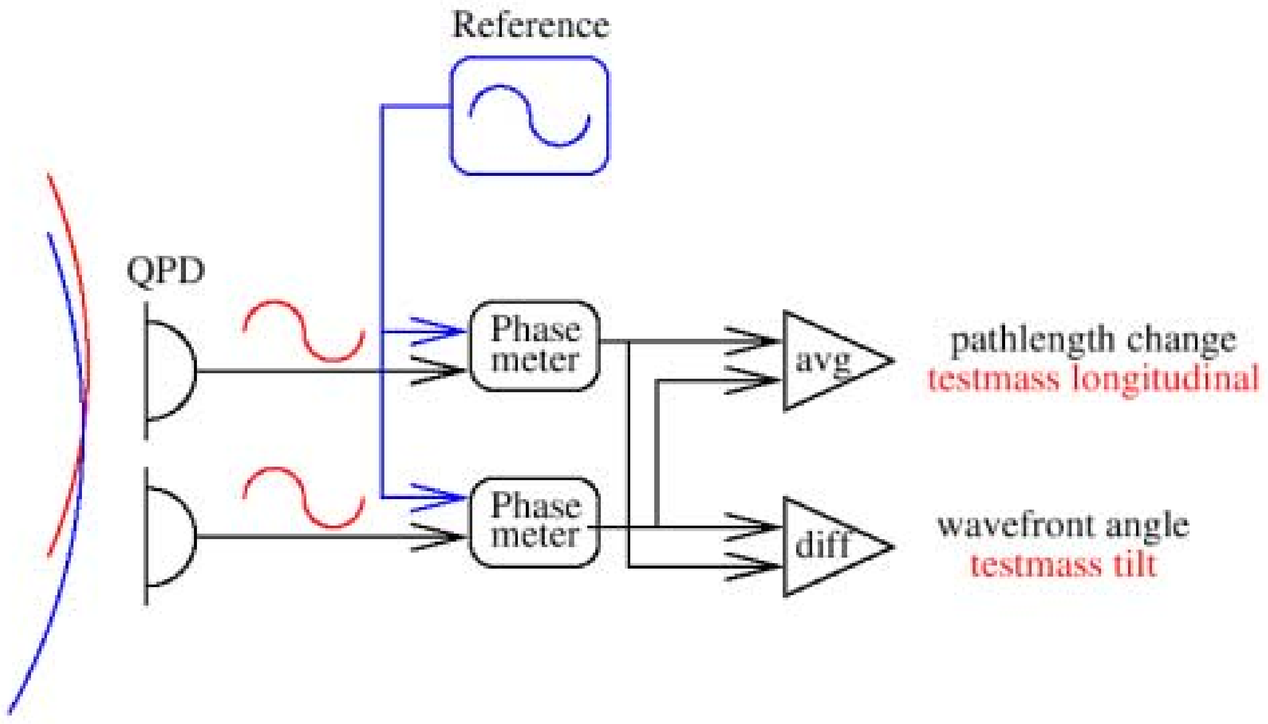
Distance measurements by means of Heterodyne interferometry



Time dependence heterodyne signal:

$$\cos\varphi = \cos\left(2\pi f_{\text{het}}\, t - \frac{2\pi x}{\lambda}\right)$$

Differential wavefront sensing



Conversion factor T/M angle ά to differential phase readout φ is approximately φ/ ά = 10^4

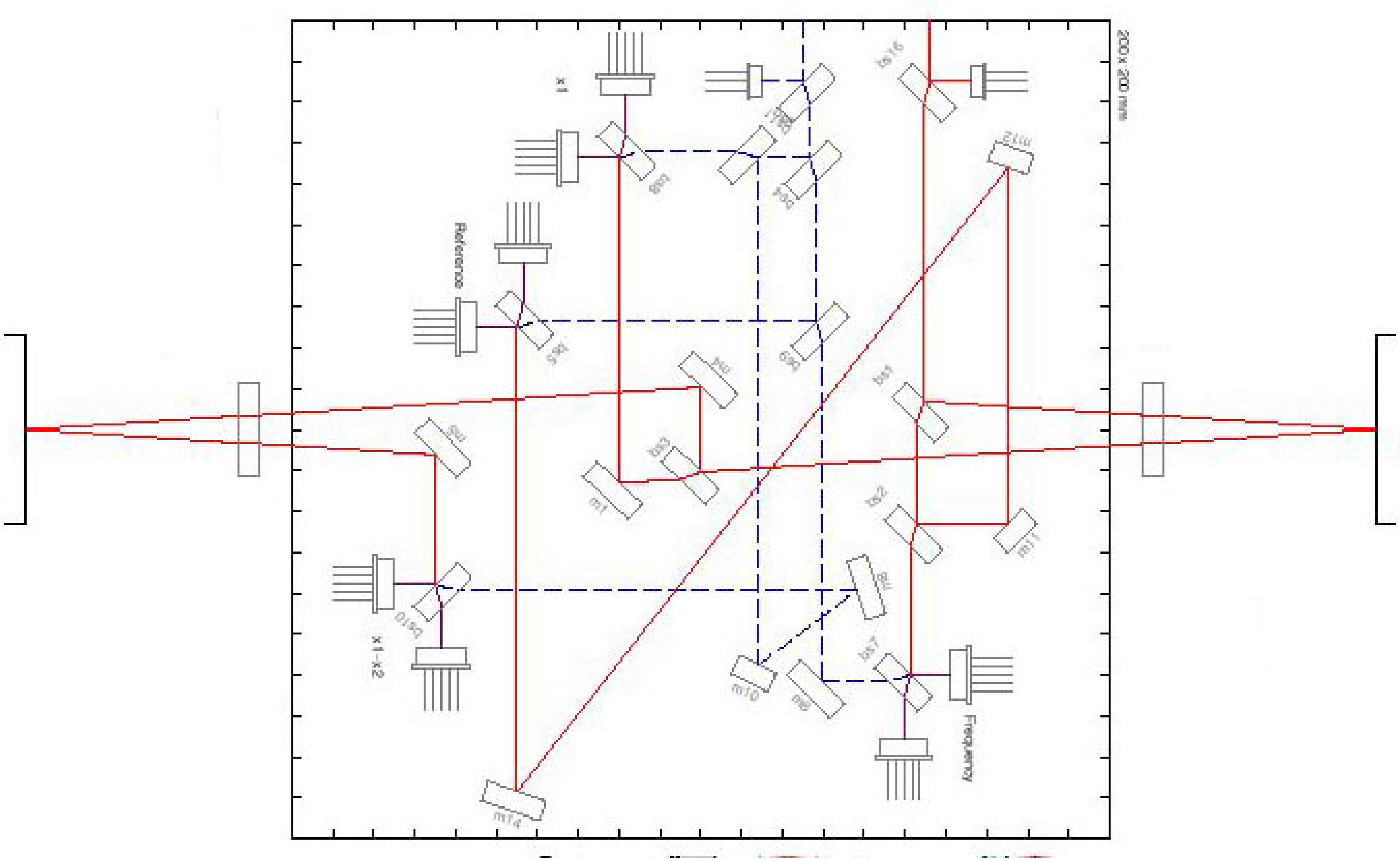
Key components OB system

- Frequency and amplitude stabilized NdYAG laser
- Fibre coupling
- Optical modulators
- Beamsplitters and other optical components
- Ultrastable optical bench and alignment techniques
- Quadrant and single element photodiodes
- Phase readout system of interferometric signals

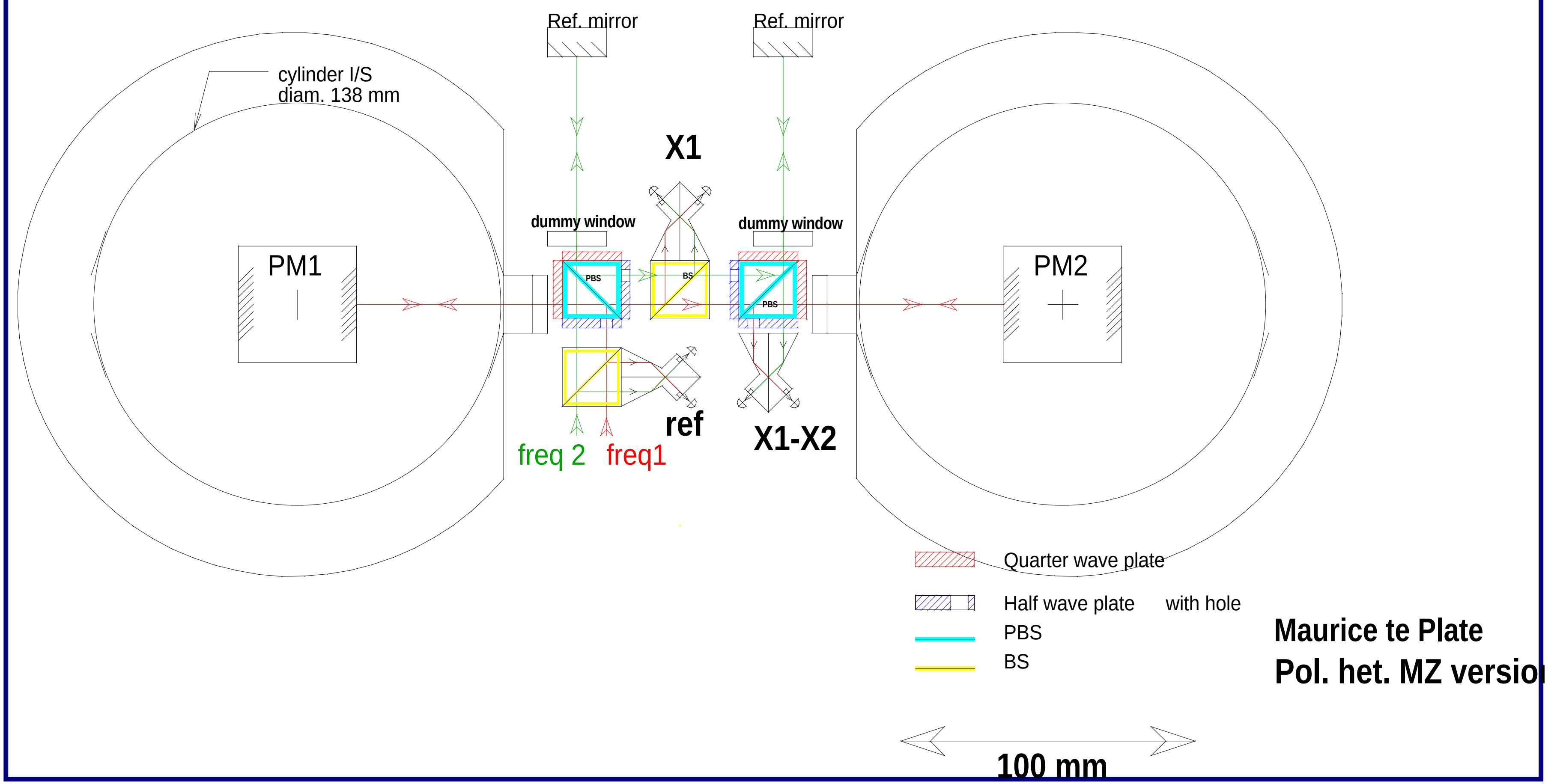
Optical design trade-off

- Polarizing Mach Zehnder interferometers
  - Compact design possible
  - Orthogonal incidence on T/M's
  - Similar type of optics as current LISA B/L optical design
  - Uncertainties on thermal stability polarizing optics
  - Long optical path length in transmission (dn/dT effects)
- Non-polarizing Mach Zehnder interferometers
  - Less risky approach:
  - No Orthogonal incidence on T/M's
  - Less compact optical design

Zig-zag Mach Zehnder (AEI) Non-polarized interferometer



Polarized Mach Zehnder (ESTEC)



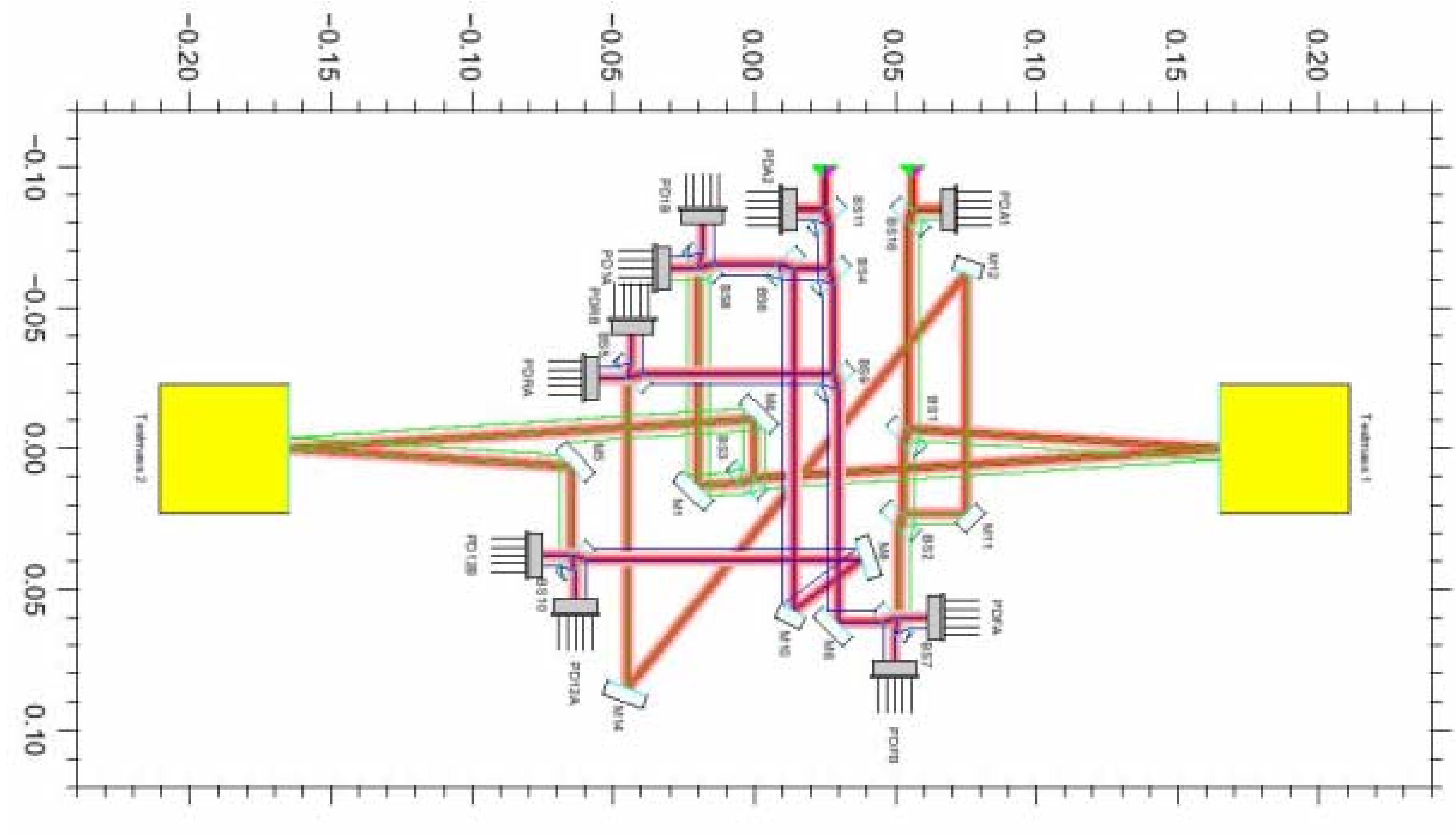
Interferometer selection criteria

Phase measurement need to be performed within 10^{-5}, which corresponds to 10pm versus 1µm

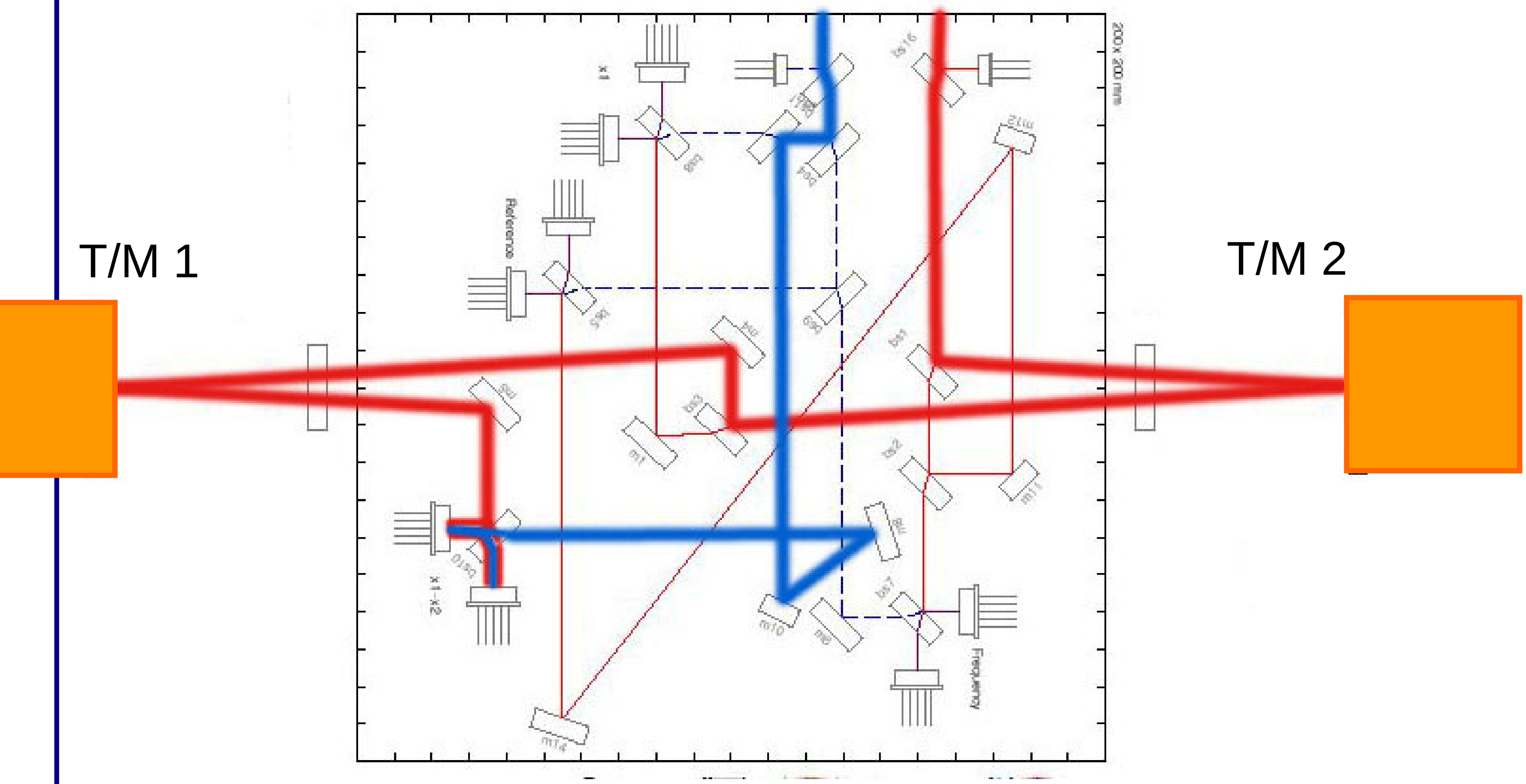
Most important Effects to be considered:

- Thermal expansion effects (CTE effects)
- Thermo-optic effects (dn/dT effects)
- Polarisation effects: e.g. stress induced birefringence

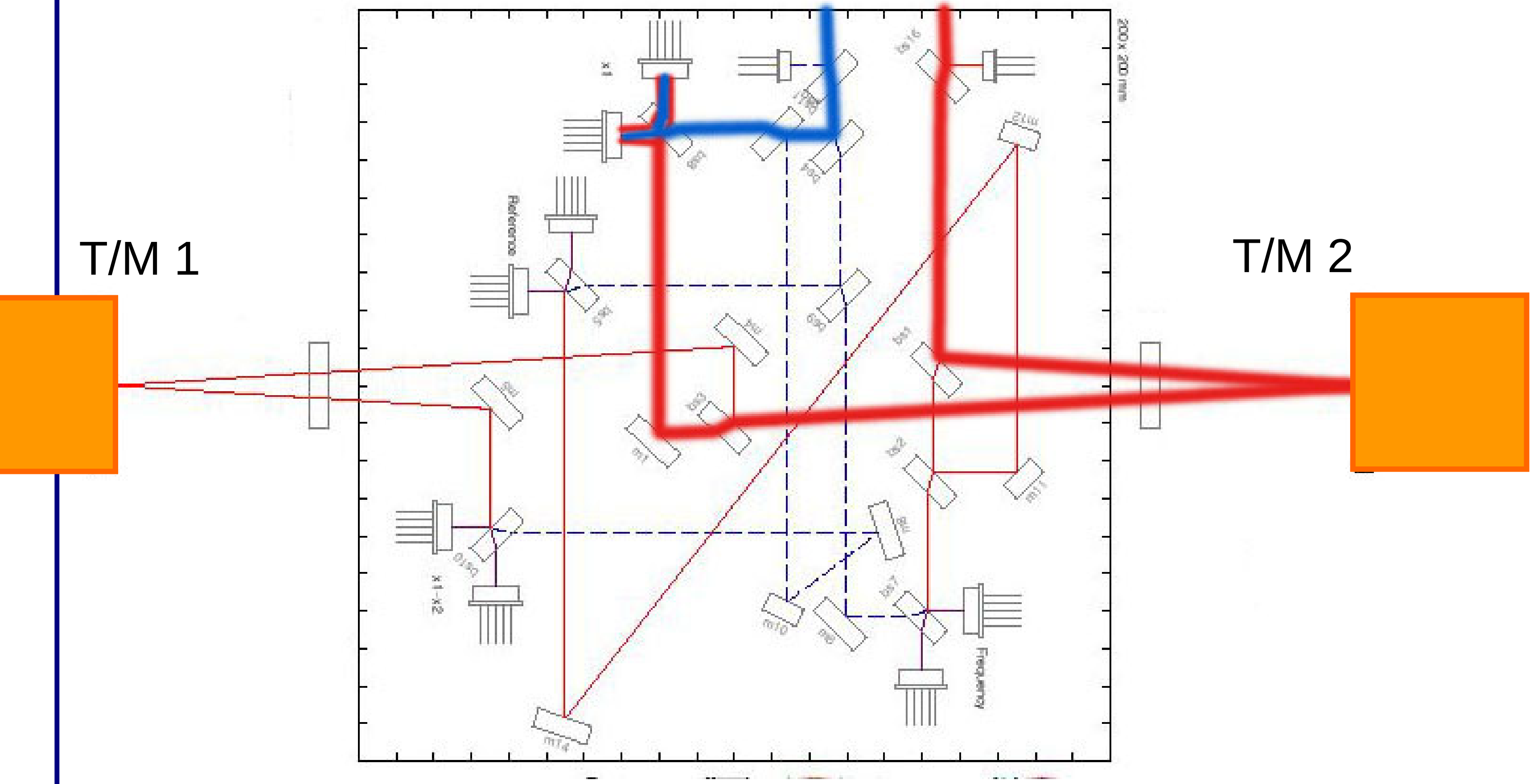
Selected interferometer design: ZIG ZAG interferometer



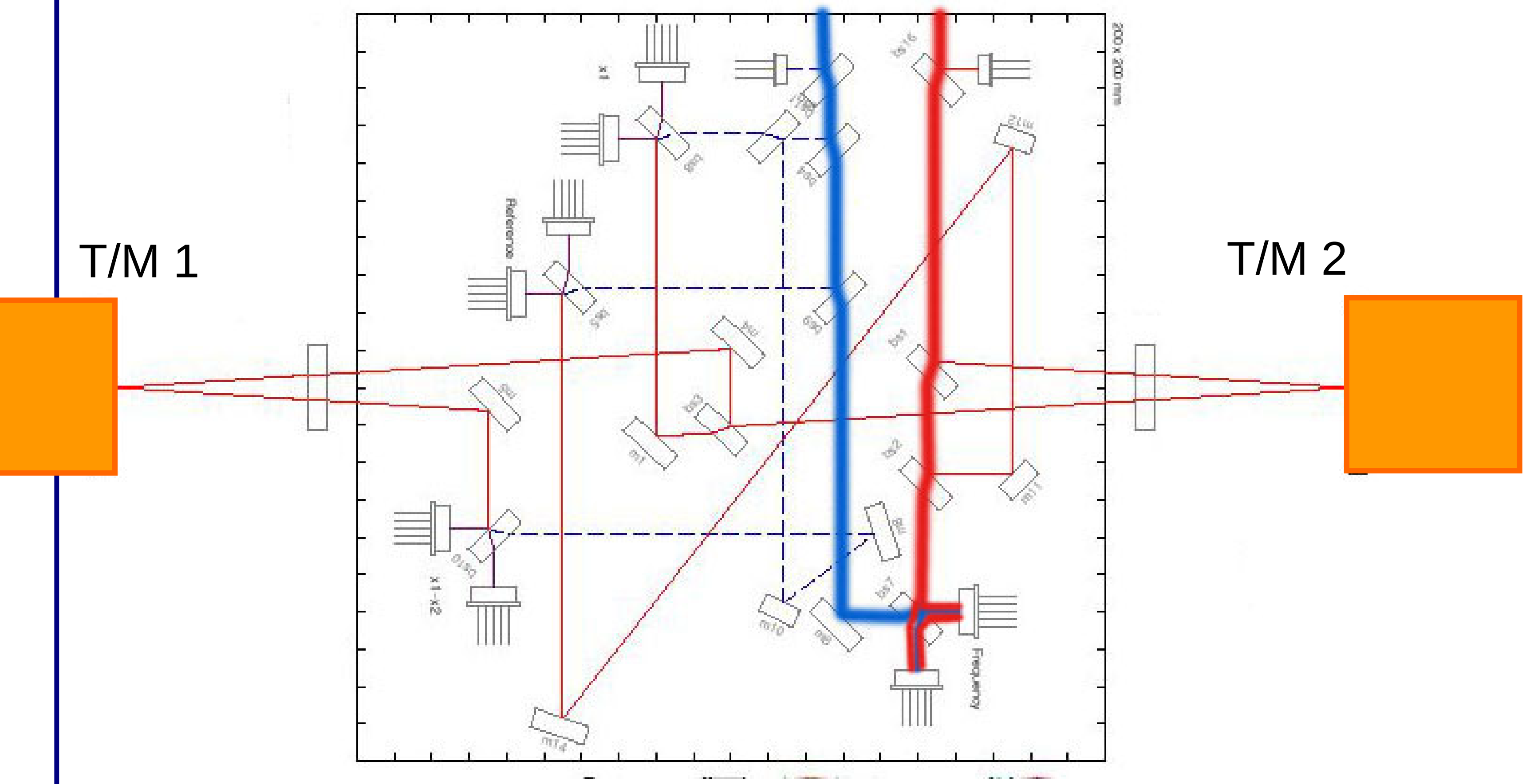
X 1 - X 2



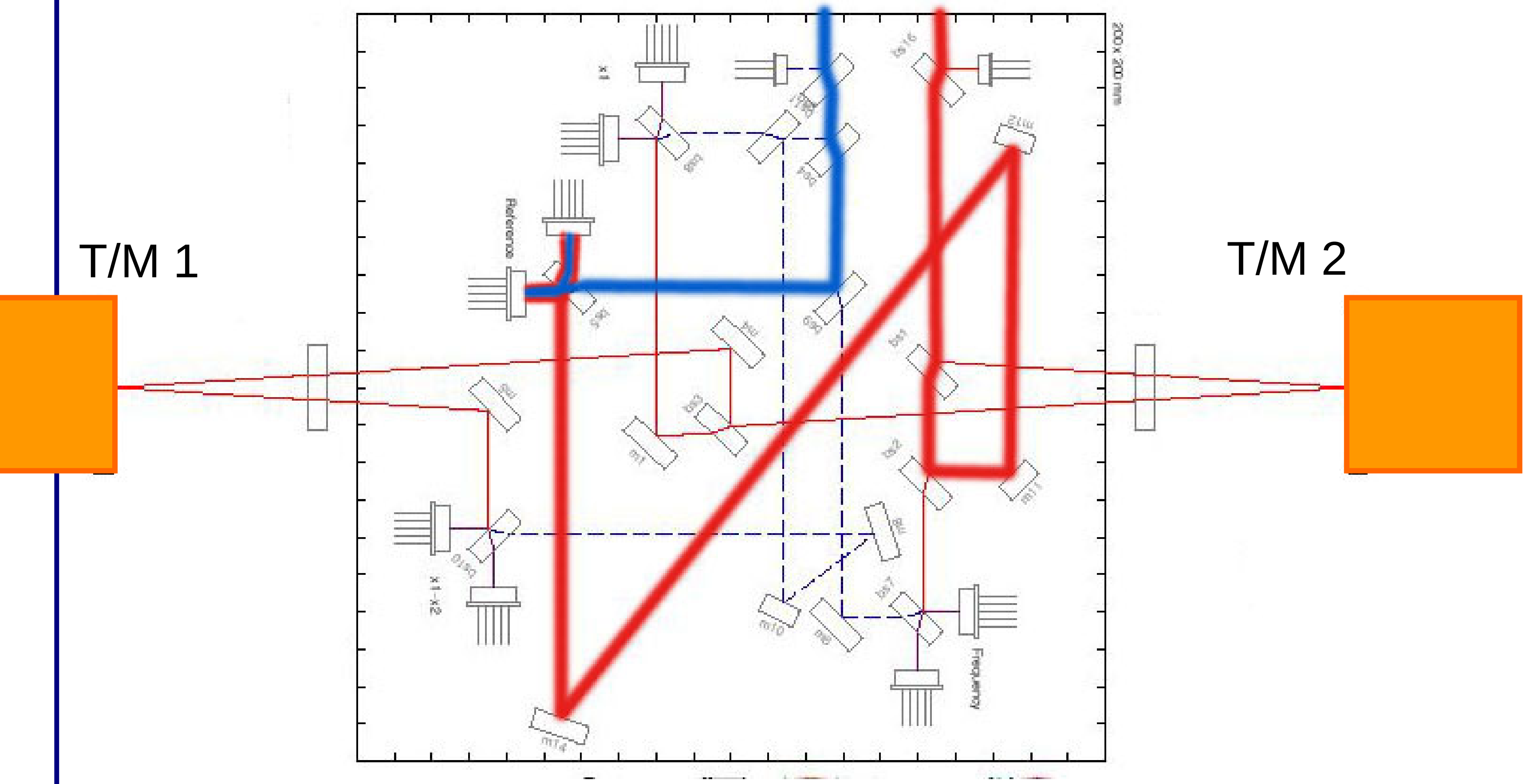
X 1



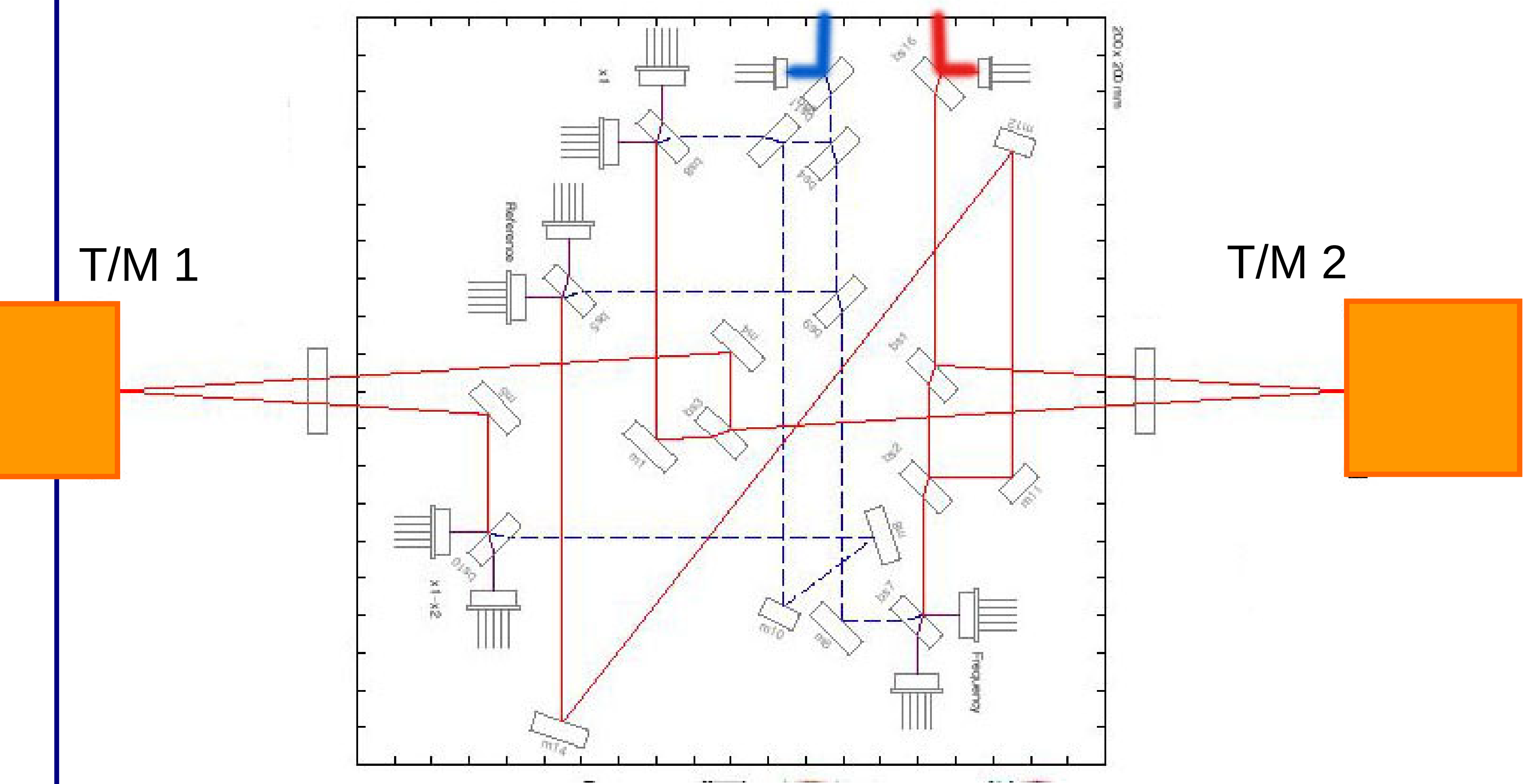
Reference phase



Unequal arm length ifo



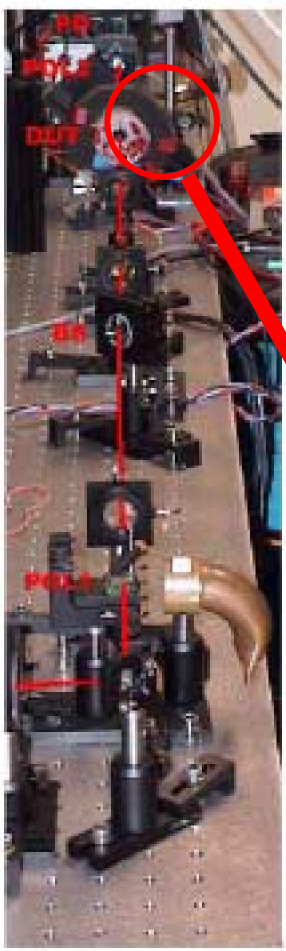
Laser monitoring detectors

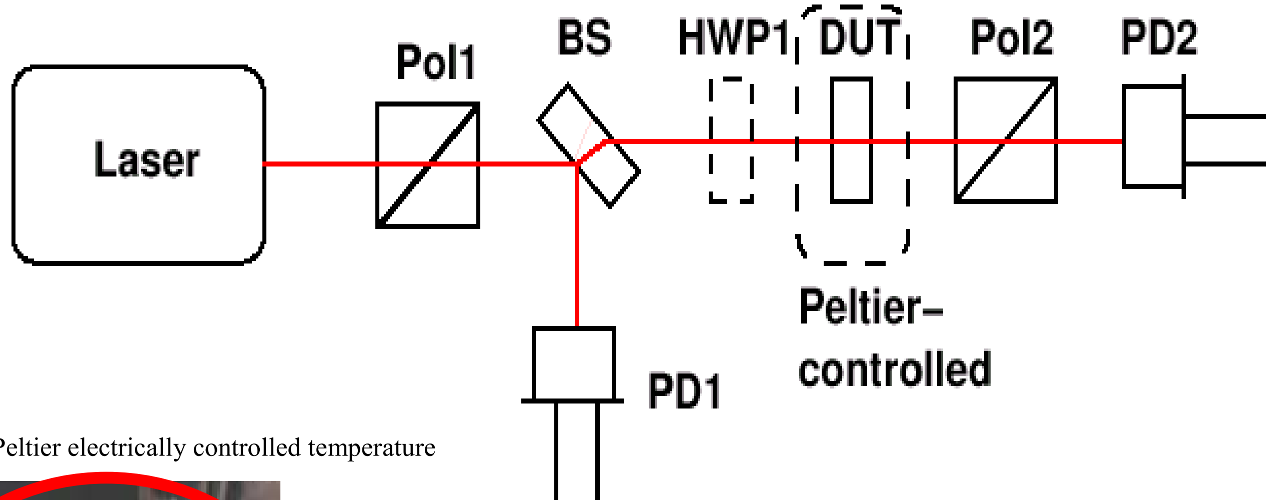


Pre-investigation experiments

1) Polarization Optics pre-investigation
2) Pre-investigation Differential wavefront sensing and phasemeter
3) Pre-investigation Optical breadboard construction using hydroxy catalysis bonding
4) Pre-investigation assembly and alignment techniques for optical bench
5) Pre-investigation TESAT laser source

1. Polarizing Optics Pre-experiment





•Peltier electrically controlled temperature

Conclusions

•Optical behaviour QWP's and HWP's changed when temperature was varied between 20 C and 40 C

•Reproducability measurements low. Highly sensitive to exact alignment components

•Stability of polarizing optical components could not be proven

•Non-polaring ifo was chosen as baseline --> less risky approach

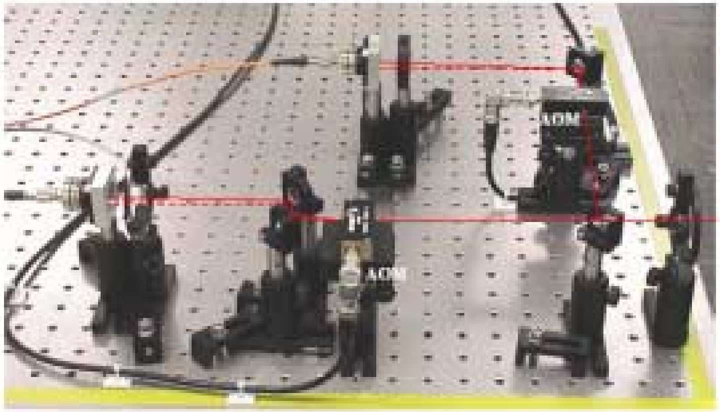
2. Pre-investigation on Differential wavefront sensing (1/3)

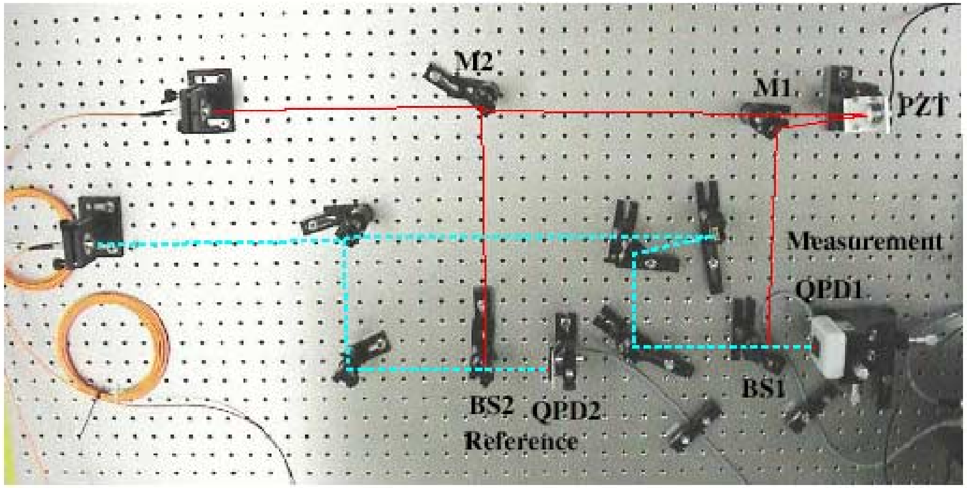
- Proto-type ìnterferometer (FFT based algorithm) was built.
  - Heterodyne freq. Generation and AOM modulation similar as planned on SMART-2
  - Fibre coupling for freq. shifted beams by means of space qualifiable components
  - Quadrant photo diodes (Si in stead of InGaAs)

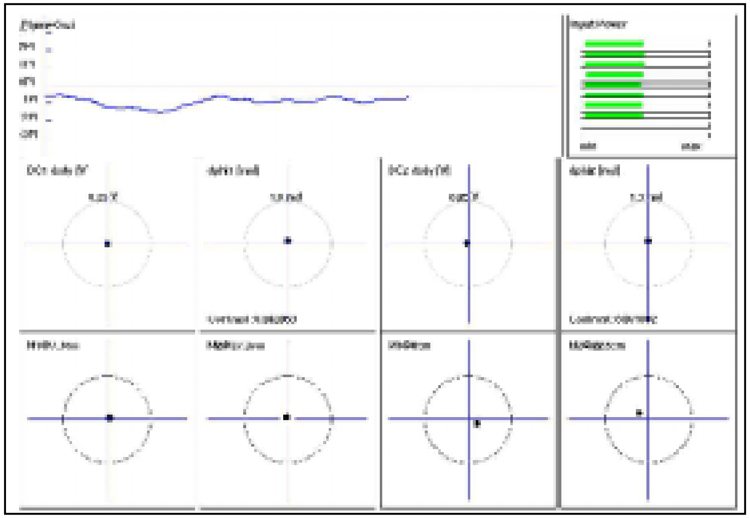
- Phase measurement system was built
  - algorithm based on FFT

$$\cos\varphi = \cos\left(2\pi f_{\text{het}}\, t - \frac{2\pi\, x}{\lambda}\right)$$

2.Pre-investigation on Differential wavefront sensing (2/3)





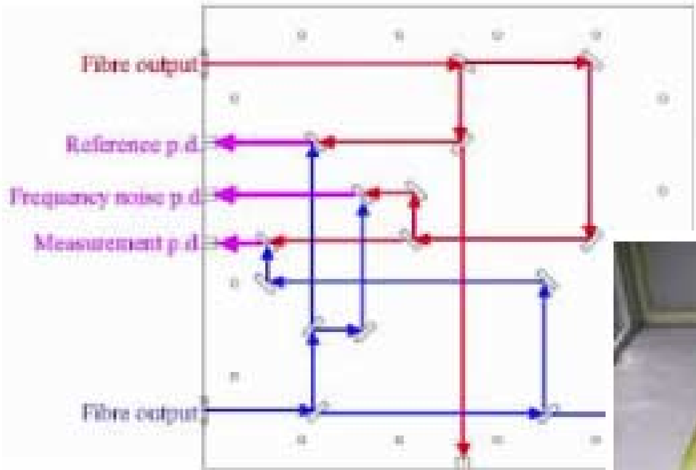


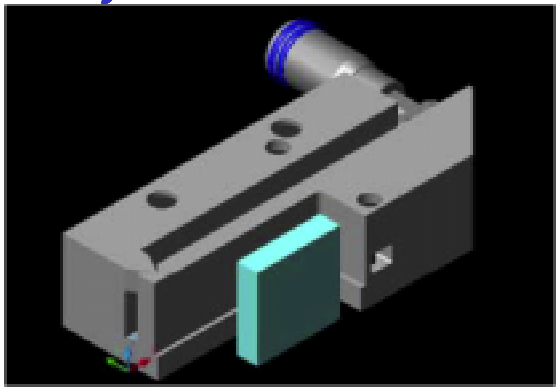
2. Pre-investigation on Differential wavefront sensing (3/3)

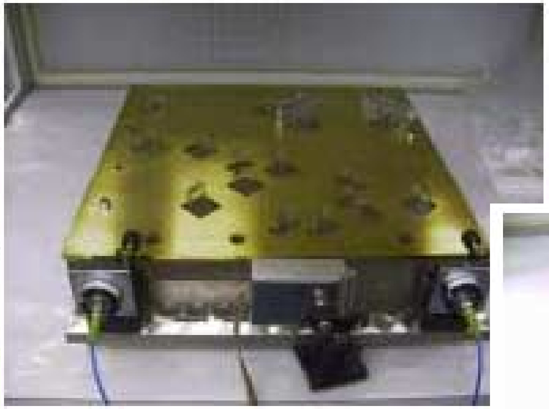
Results:

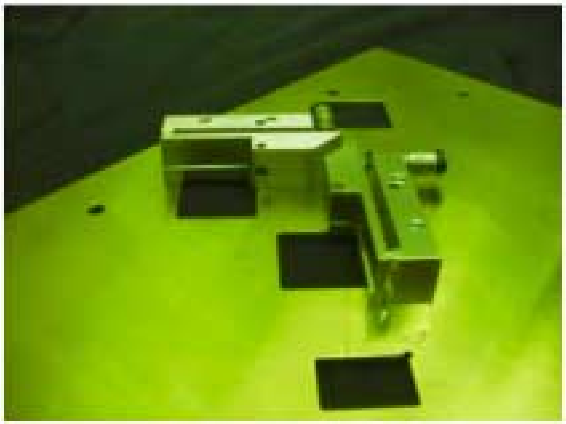
- FFT based phasemeter system works fine (performance will exceed requirements)
- Very useful knowledge was gained concerning the assembly and alignment of a heterodyne interferometer similar to the SMART-2 ifo.
- Differential wavefront sensing was verified quantitatively. Results corresponded well to theory

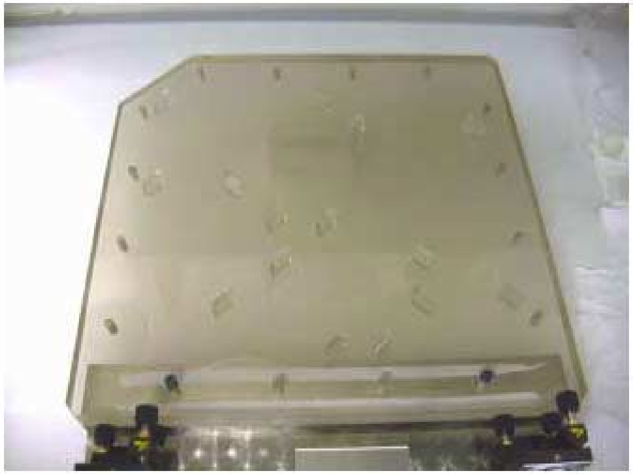
3. Pre-investigation Optical breadboard construction using hydroxy catalysis bonding (1/2)







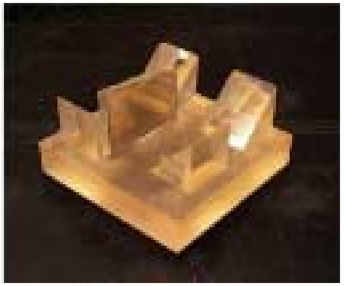


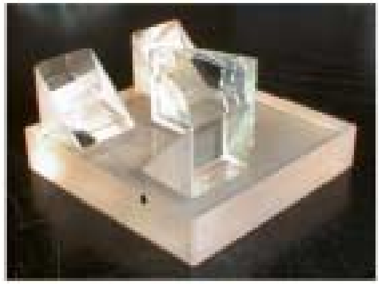


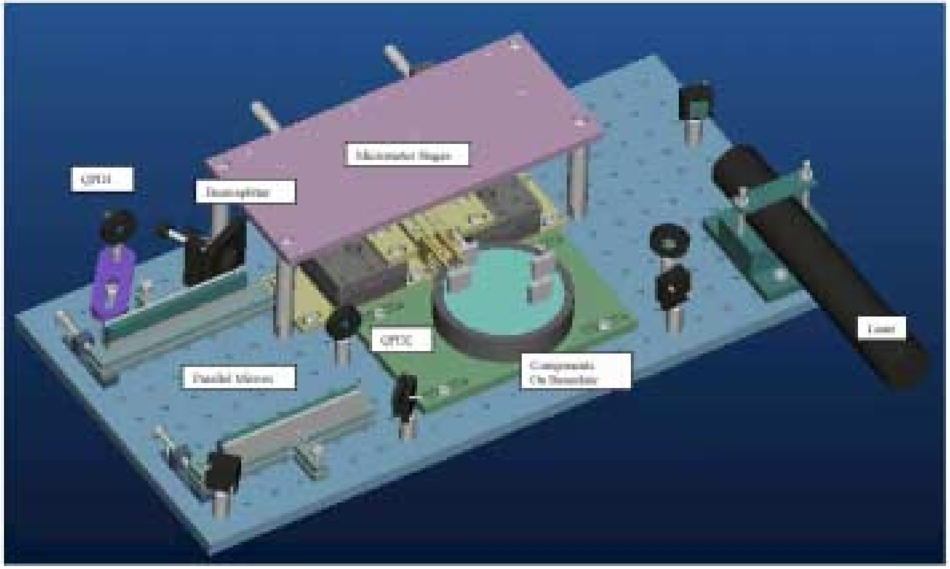
3. Pre-investigation Optical breadboard construction using hydroxy catalysis bonding (2/2)

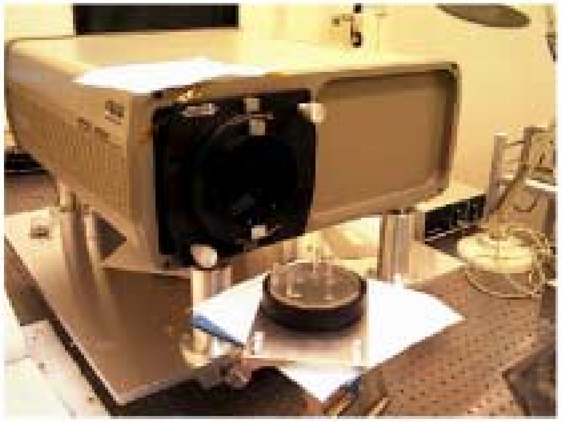
- Primary goal of producing a hydroxy catalysis bonded interferometer in general form appropriate to SMART-2 ifo has been successfully completed
- Heterodyne drive system and associated phase read-out has been succesfully completed and verified
- Further investigations are needed concerning the stability of the interferometry system (elimination of external noise sources)

4. Pre-investigation assembly and alignment techniques for optical bench (1/2)





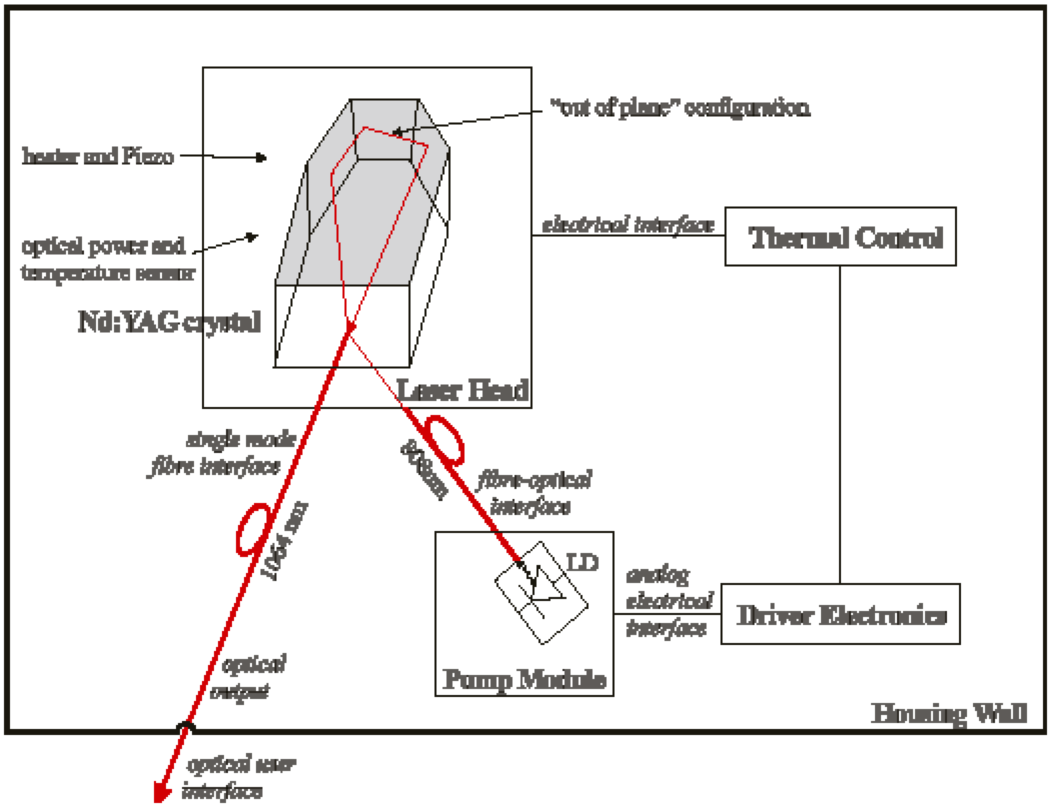


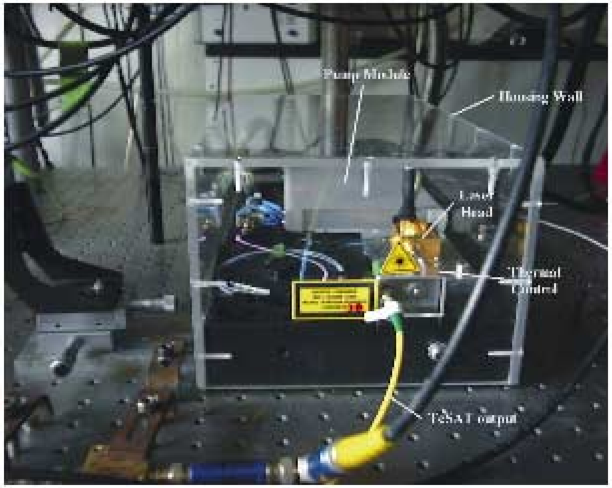


4. Pre-investigation assembly and alignment techniques for optical bench (2/2)

- Hydroxy catalysis bonding can be performed successfully
- QPD alignment technique (using DWS) is promising candidate for alignment EM OB during assembly
- Alignment techniques developed produce levels of alignment very close to those required to produce a viable optical bench
- Techniques developed can be applied successfully to EM OB

5. Pre-investigation TESAT laser source (1/2)

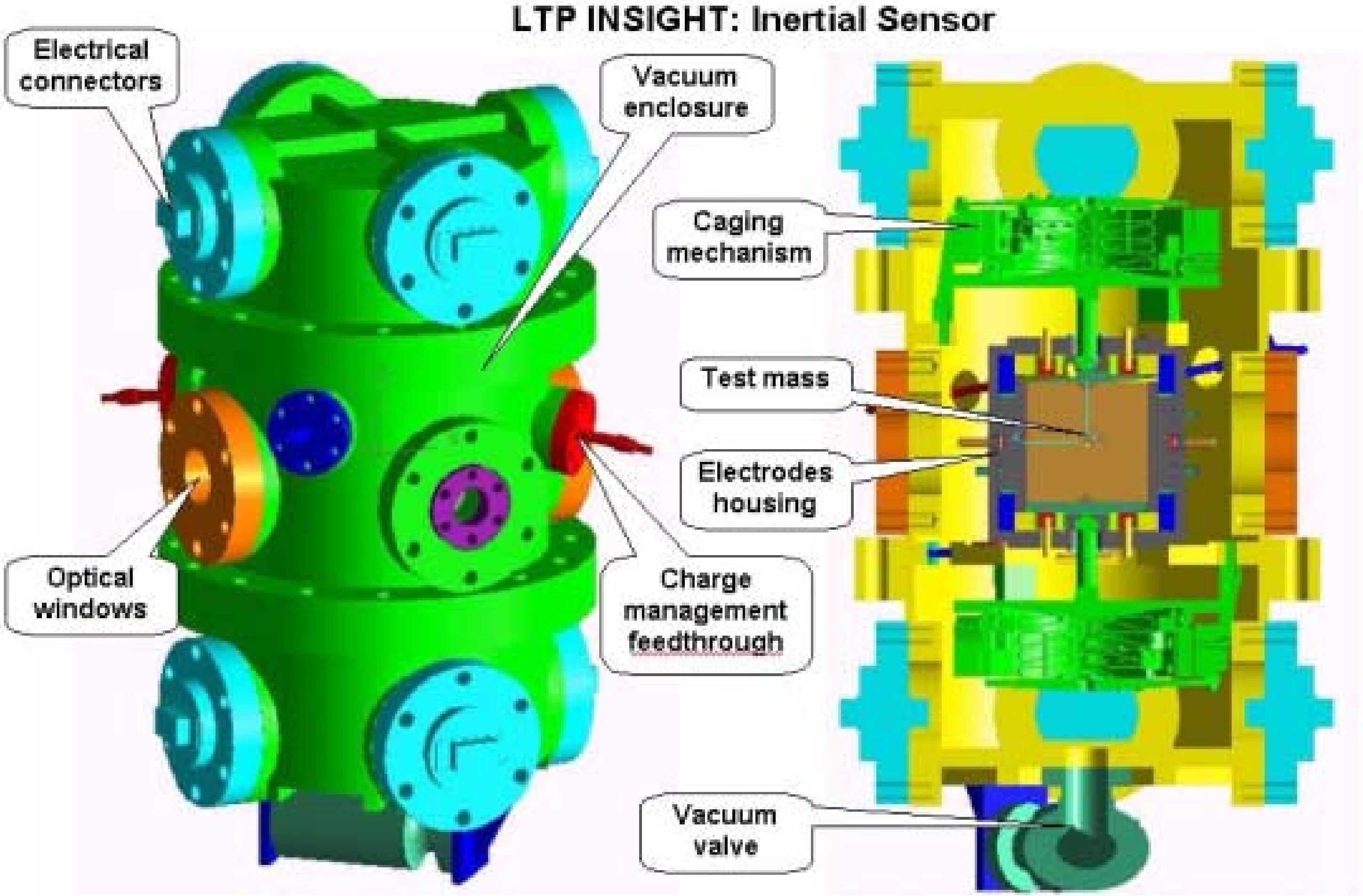




5. Pre-investigation TESAT laser source (2/2)

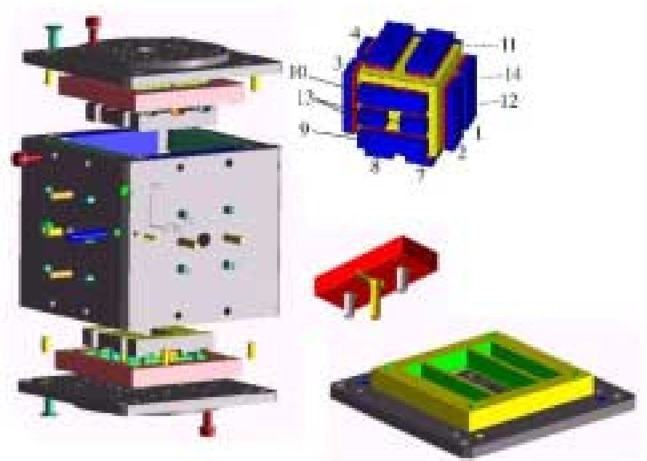
- TESAT laser is well suited for SMART-2 (possibly also for LISA and DARWIN)
- Free running stability: Freq. stability better than 1e-9 over 1...1000 s, max drift 330 KHz/hour.
- Frequency stabilization against stable reference (CORE system) was demonstrated (better than 7e-14 over 1....2000 s, Max drift < 4 Hz/hour)
- TESAT laser offers:
  - Space qualified laser head
  - Pump module, electronics and optical elements are planned to be qualified soon
- TESAT laser is currently being tested in more detail at AEI

Inertial Sensor (IRS)

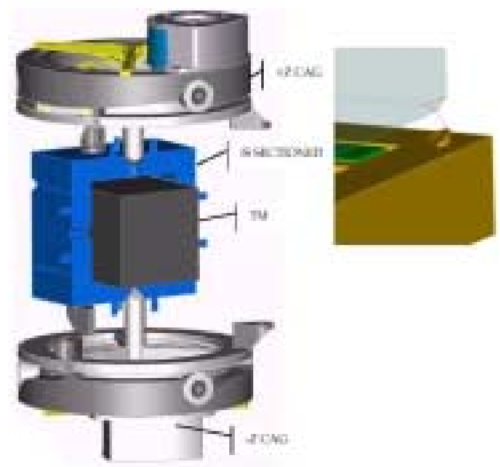


Inertial sensor subsystems:

Subsystems are:



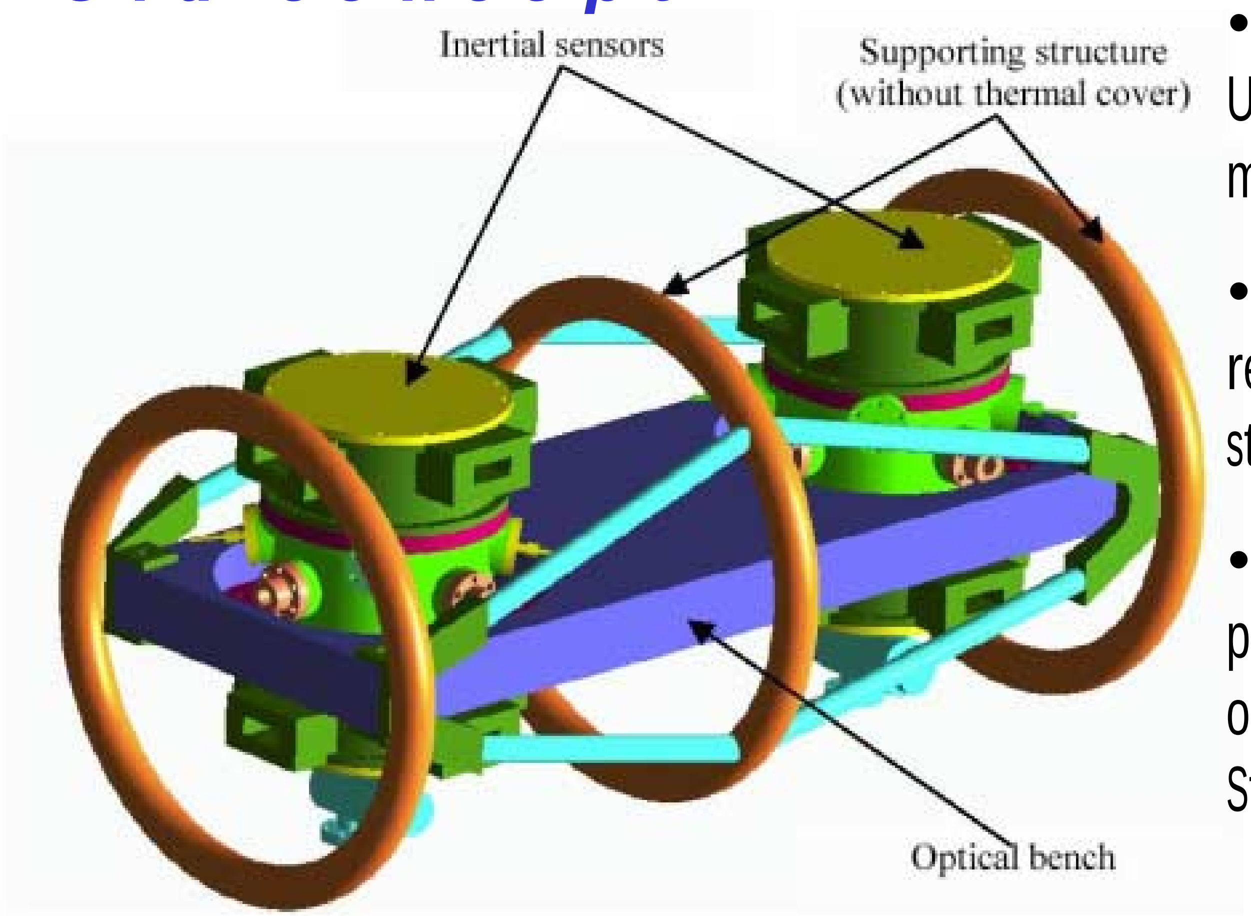
IRS electrode housing



IRS caging mechanism

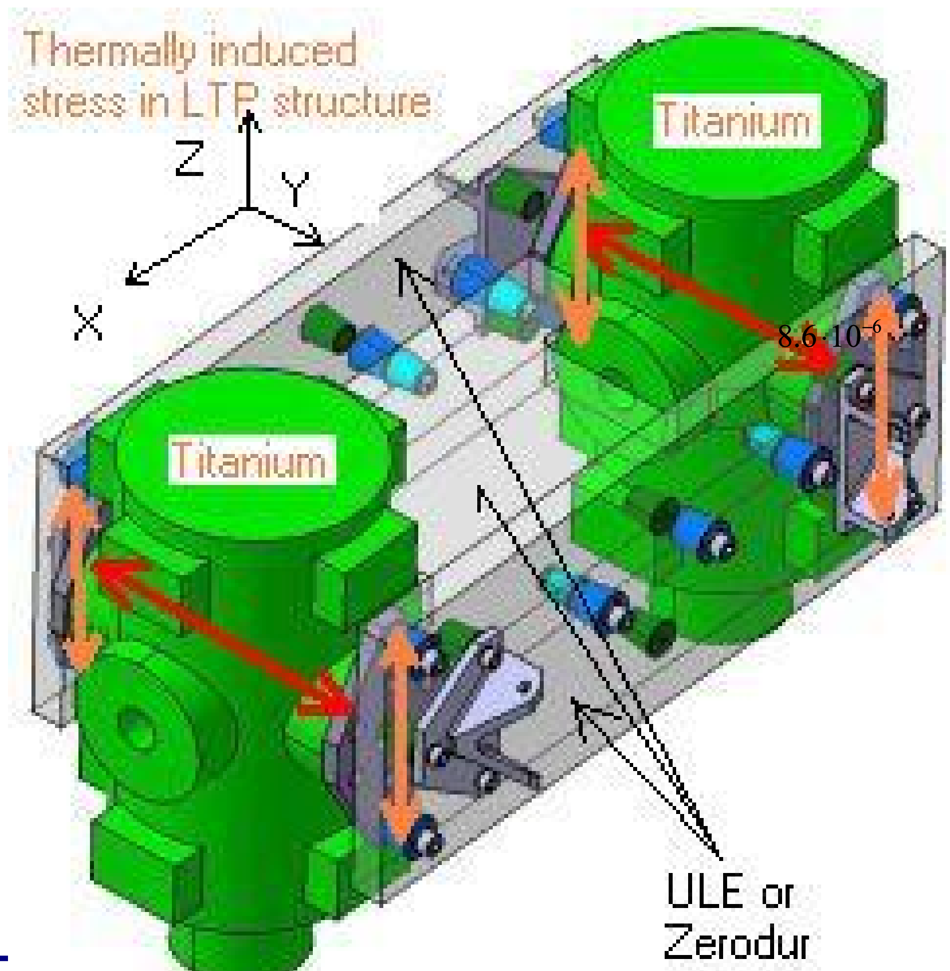
IRS charge management system

LTP mechanical aspects
Old concept



- Design not feasible in ULE/Zerodur since both materials are very brittle
- Insufficient reinforcement of structure (launch load)
- Bolting of IRS's not possible in ULE/Zerodur optical bench: Mech. Stress too high

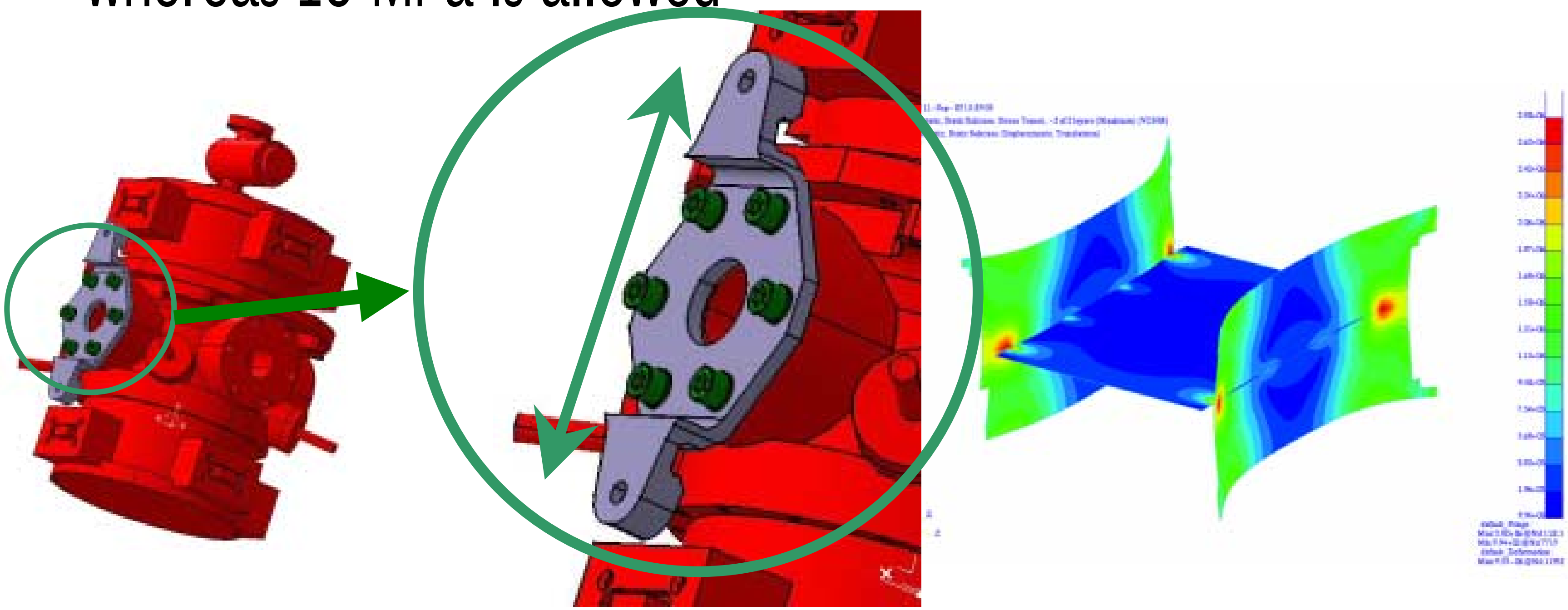
Interface OB-IRS (1/2)



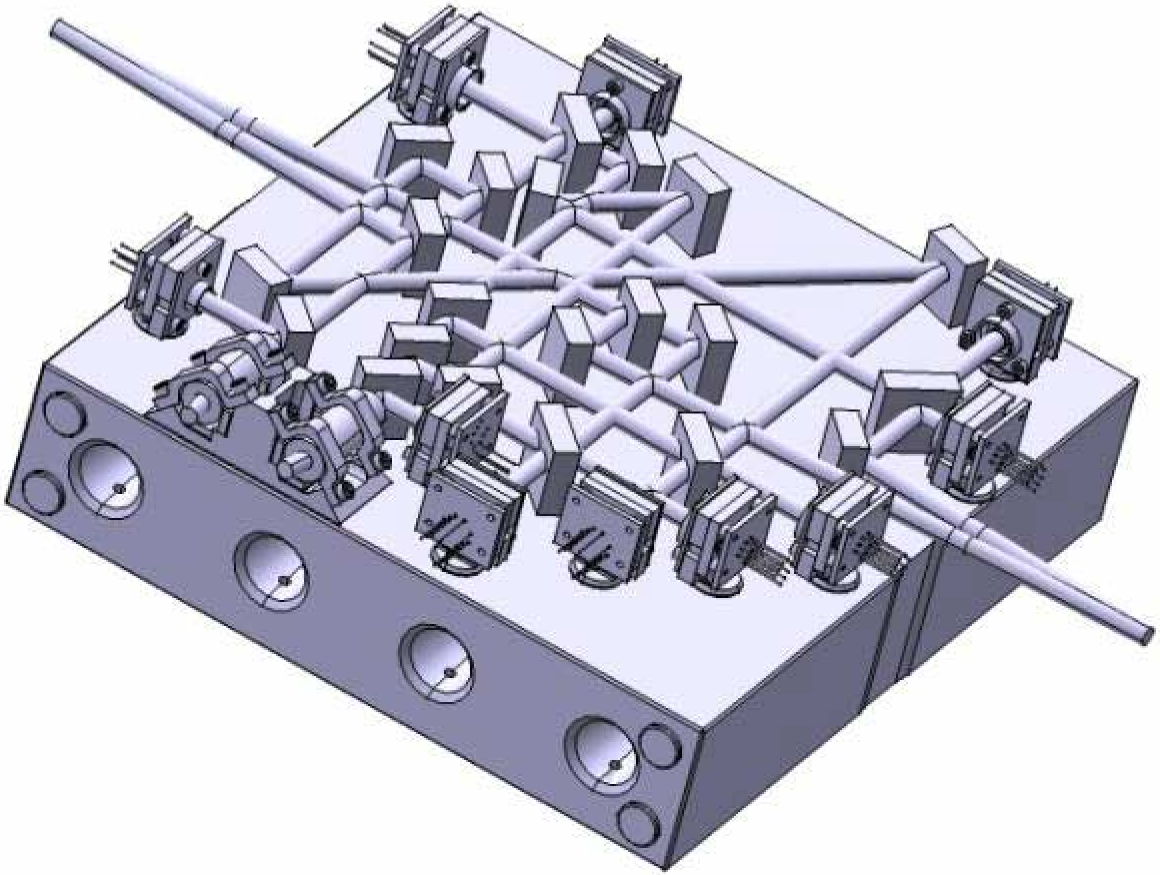
- IRS made of Titanium ($CTE \approx 8.6 \cdot 10^{-6}$)
- OB is made of
- ULE/Zerodur ($CTE \approx 0.1 \cdot 10^{-6}$)
- Thermally induced stress in Y and Z direction → Need for "flexible" mounting

Interface OB/IRS (2/2)

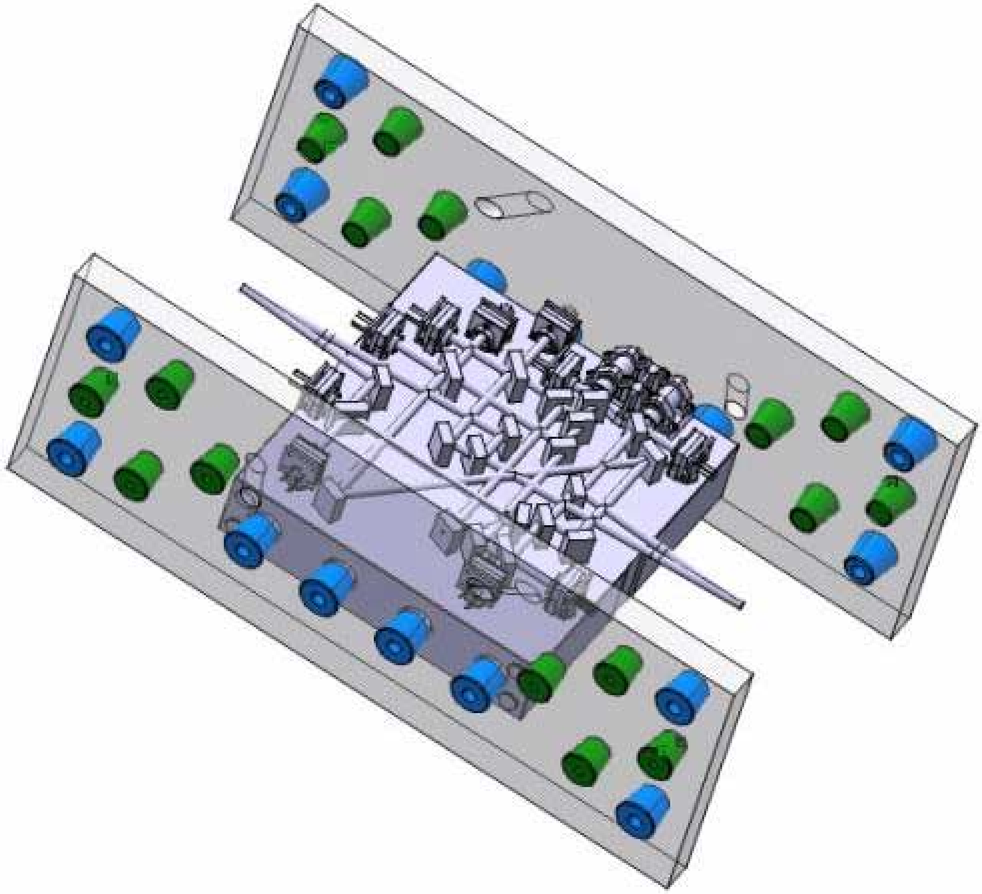
- I/F consolidated. FEM analysis OK.
- Induced stresses < 2 MPa (assuming point fixation) whereas 10 MPa is allowed



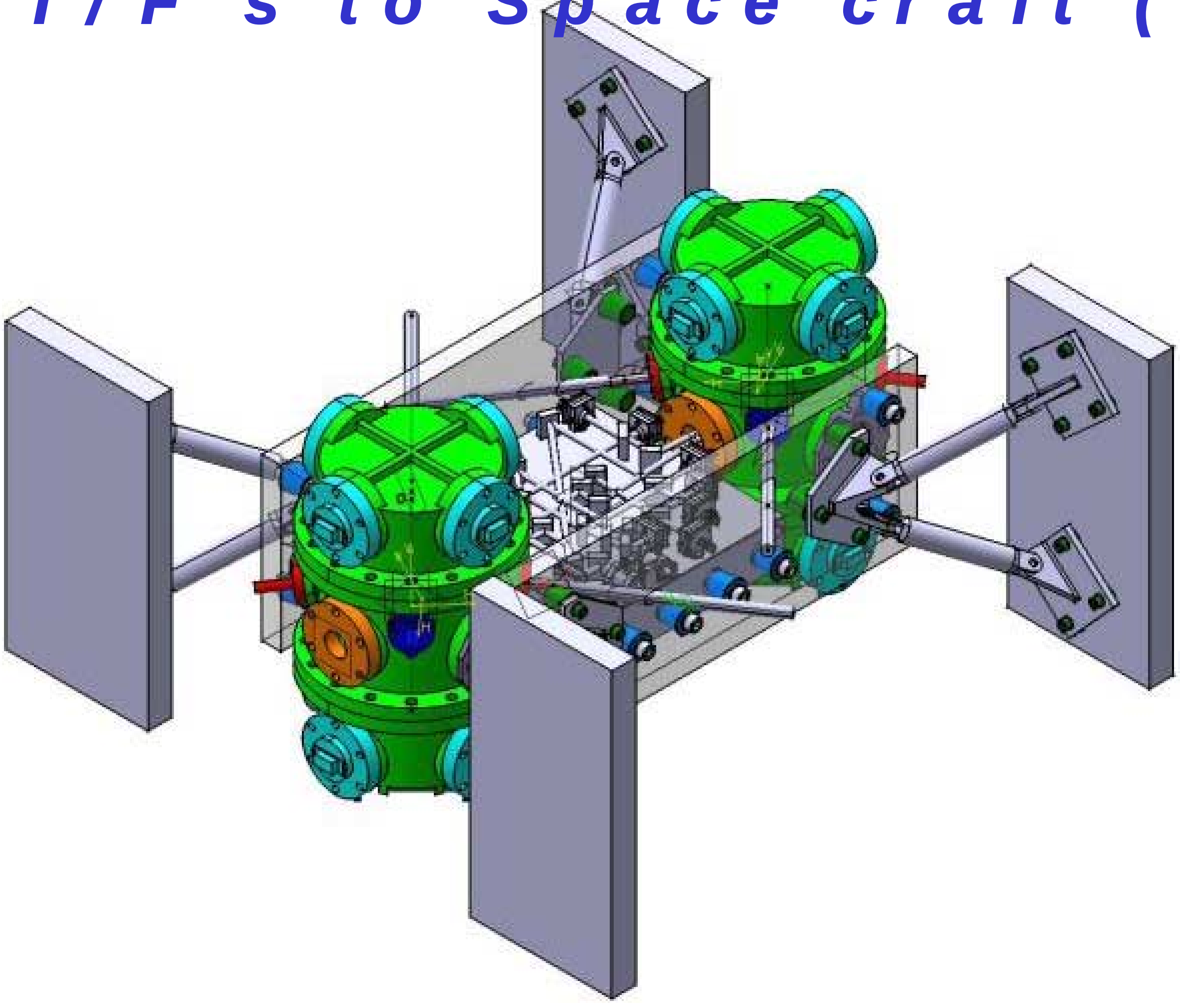
EM Optical Bench only



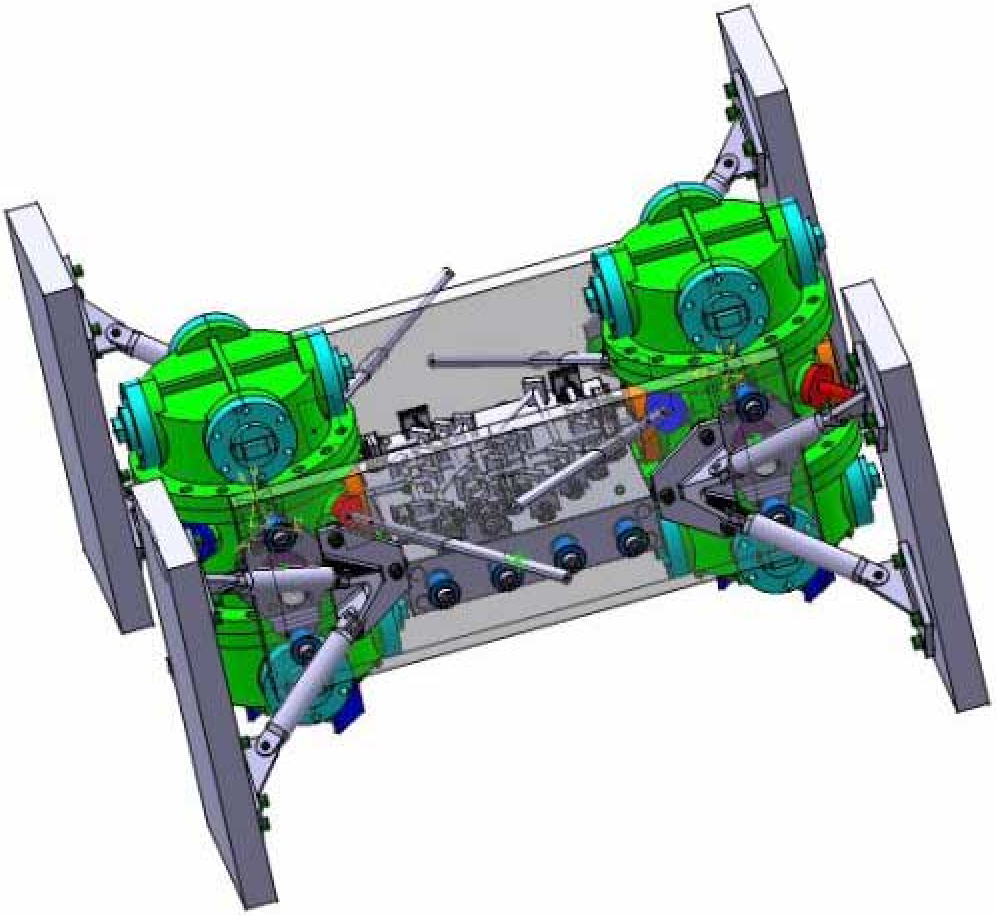
EM Optical Bench with reinforcement slabs



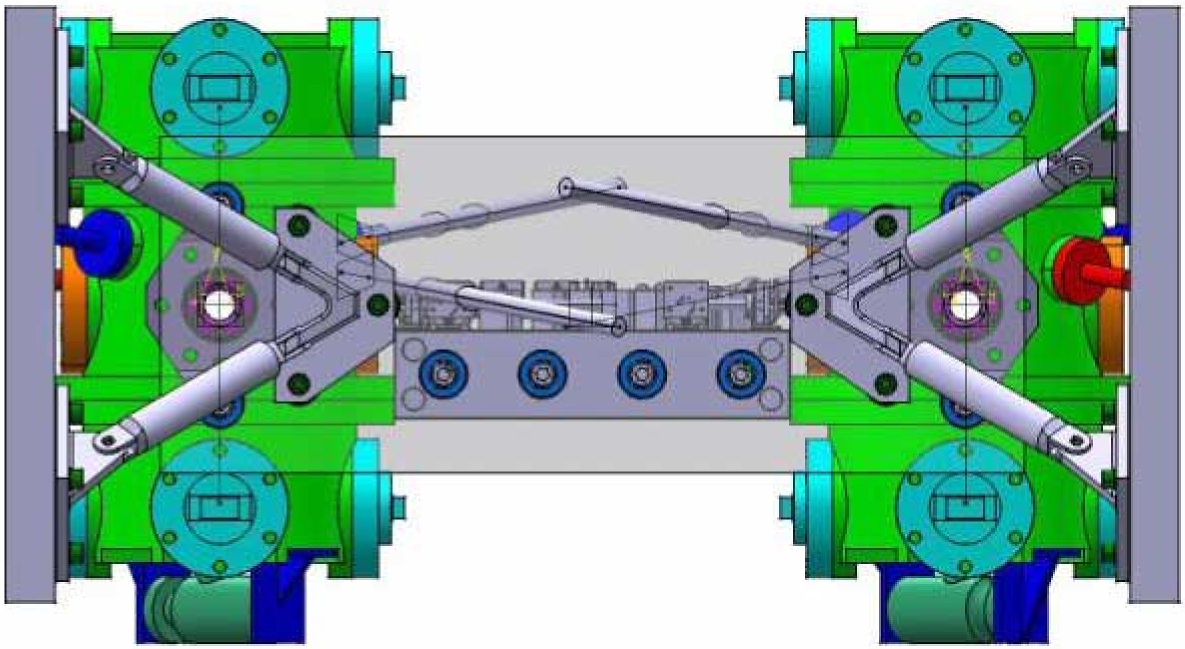
Complete LTP concept incl. I/F's to Space craft (1/4)



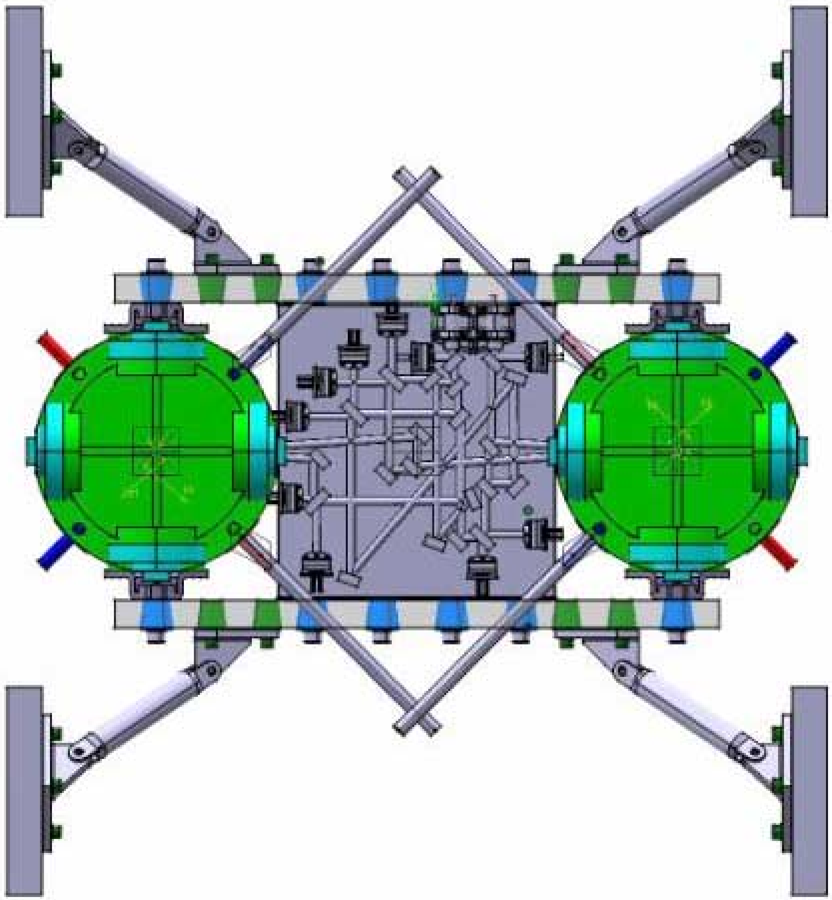
Complete LTP concept incl. I/F's to Space craft (2/4)



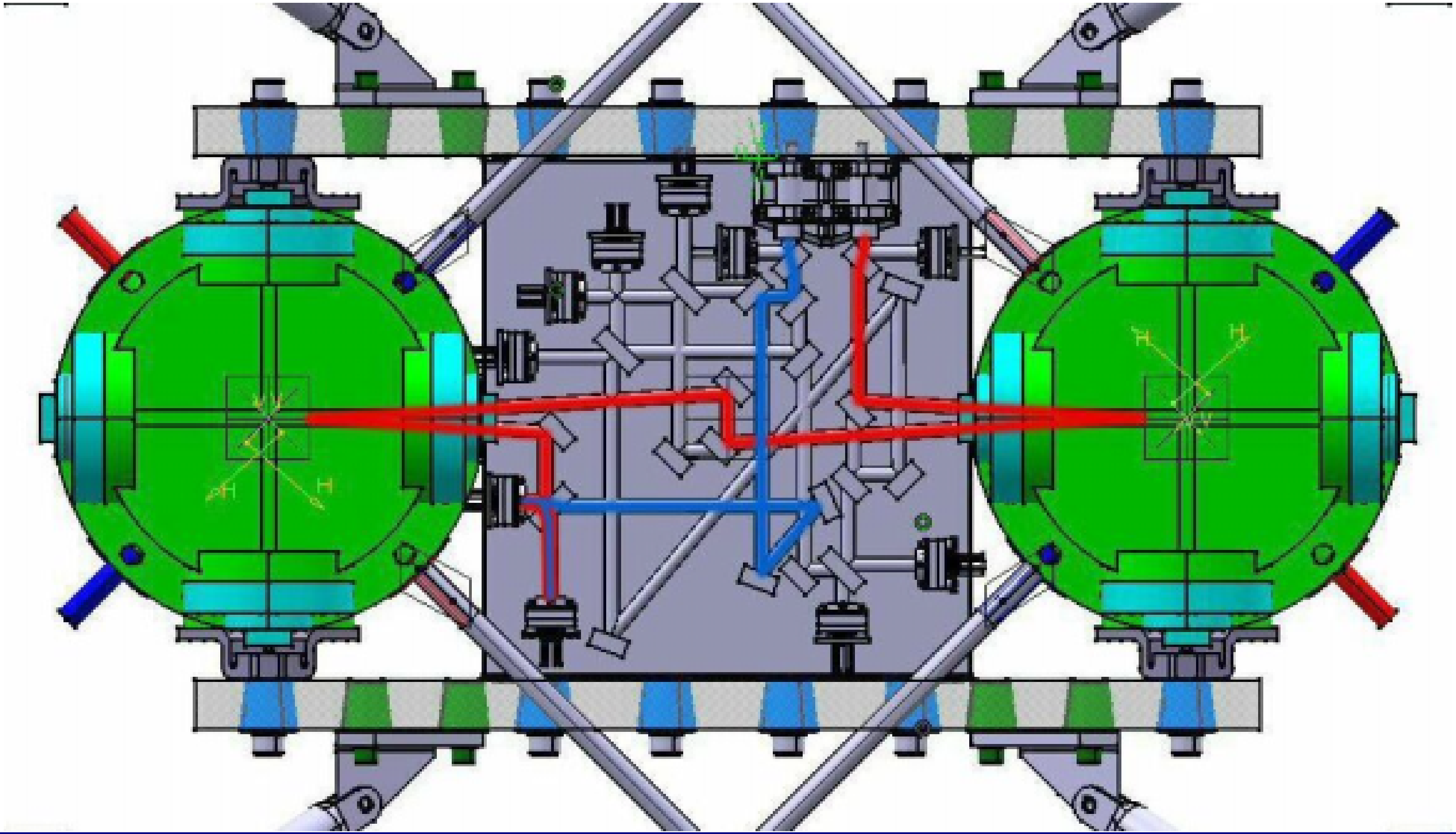
Complete LTP concept incl. I/F's to Space craft (3/4)



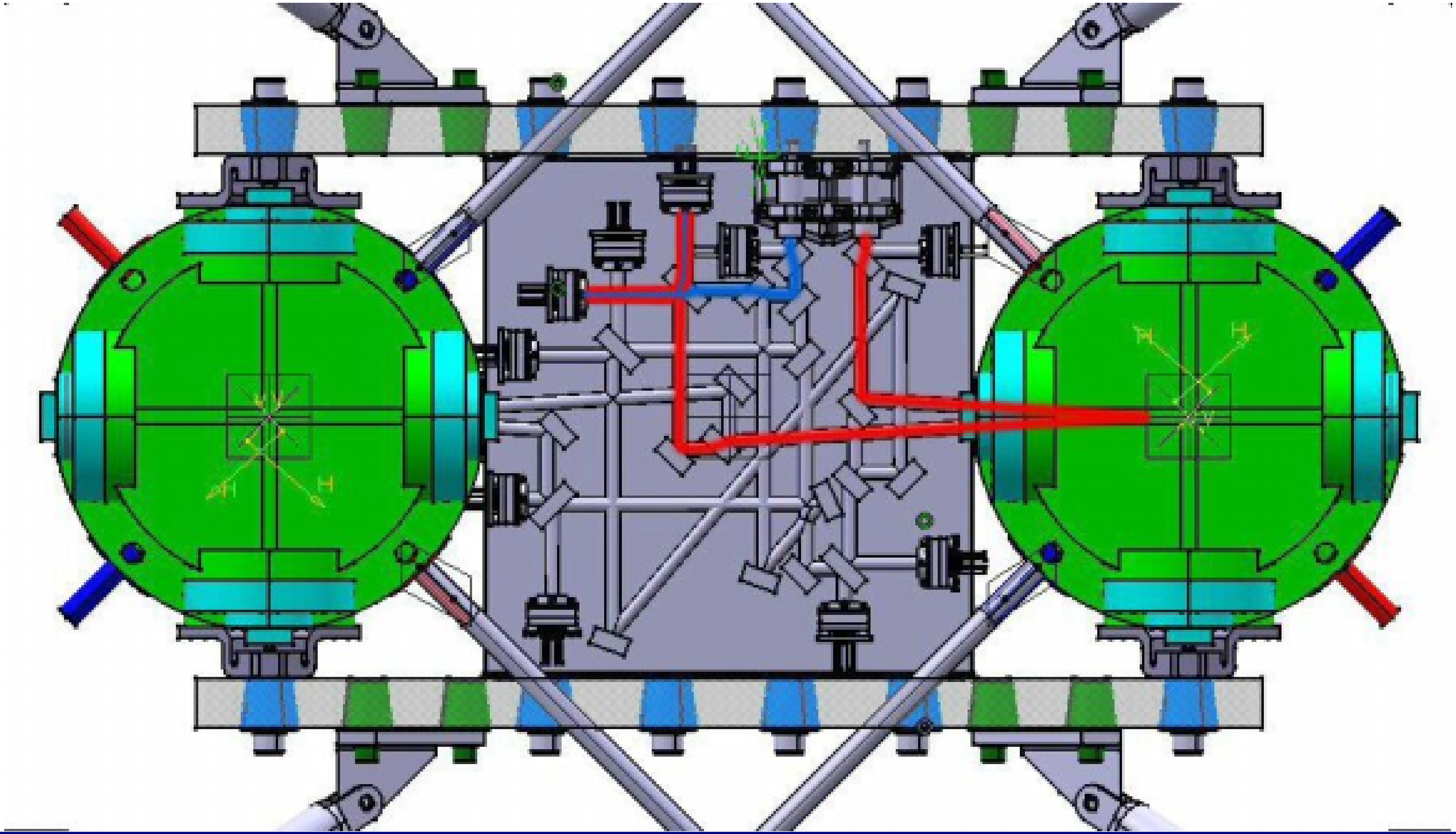
Complete LTP concept incl. I/F's to Space craft (4/4)



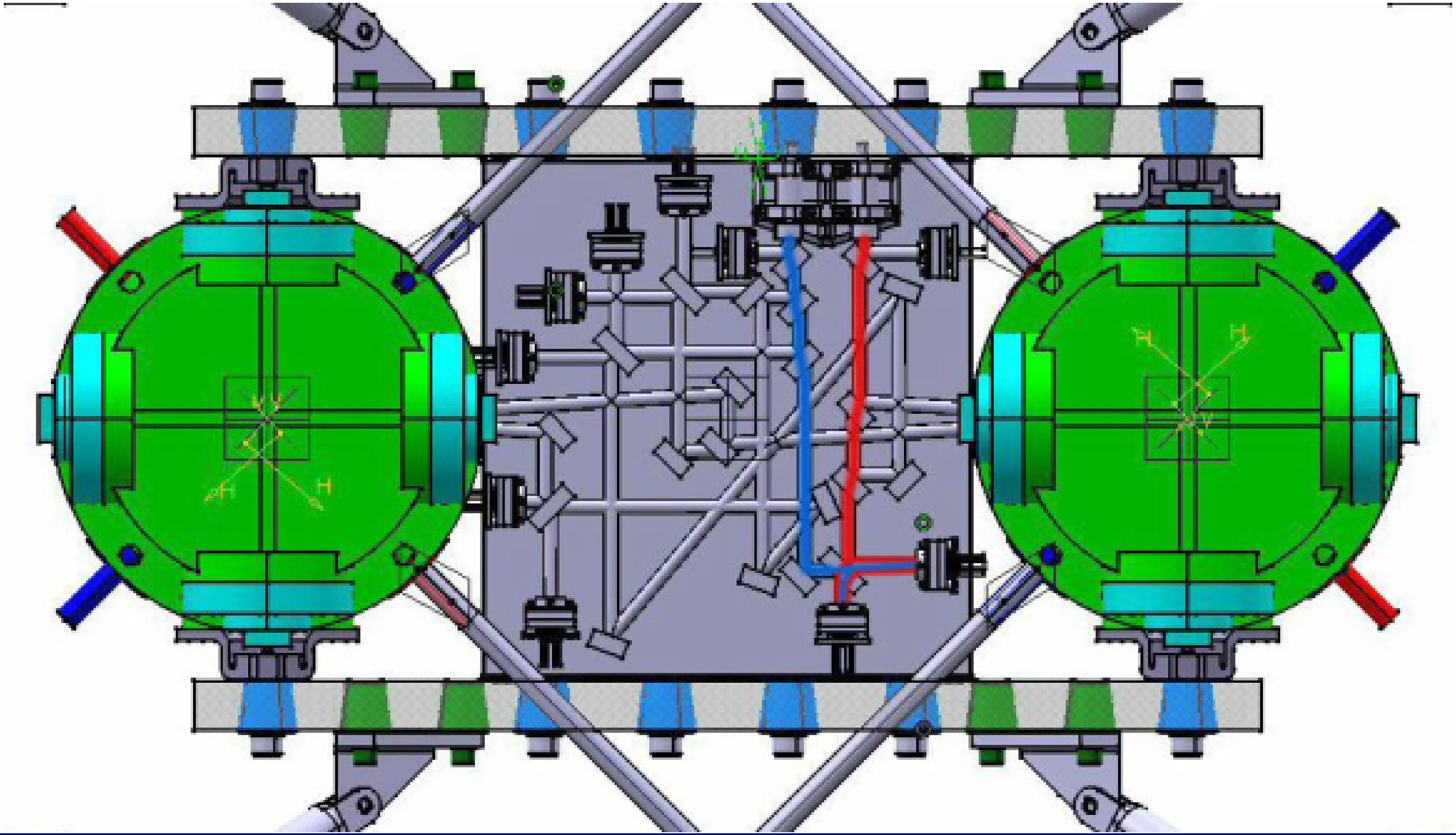
Optical Bench optical paths X1 – X2



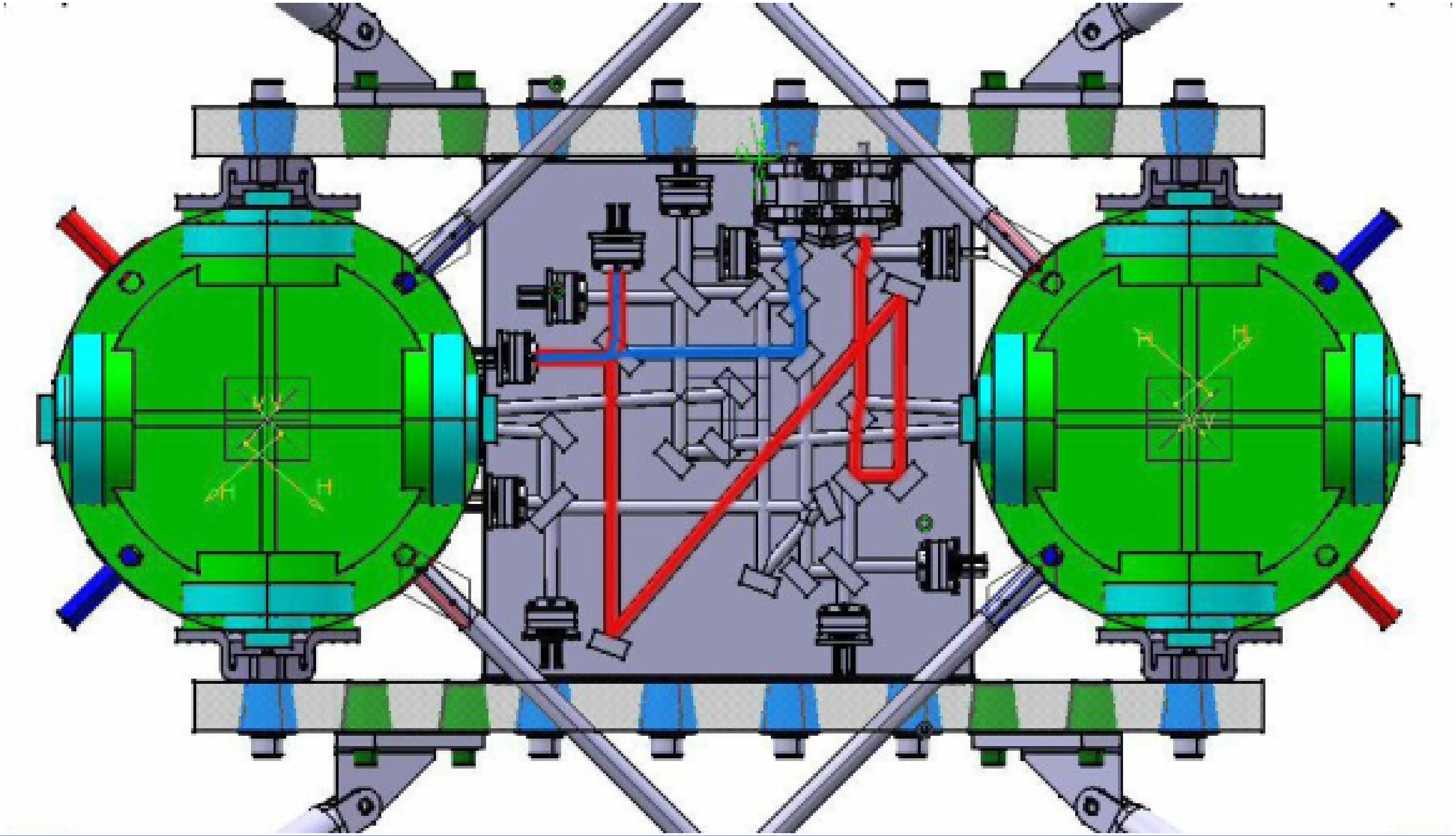
Optical Bench optical paths X 1



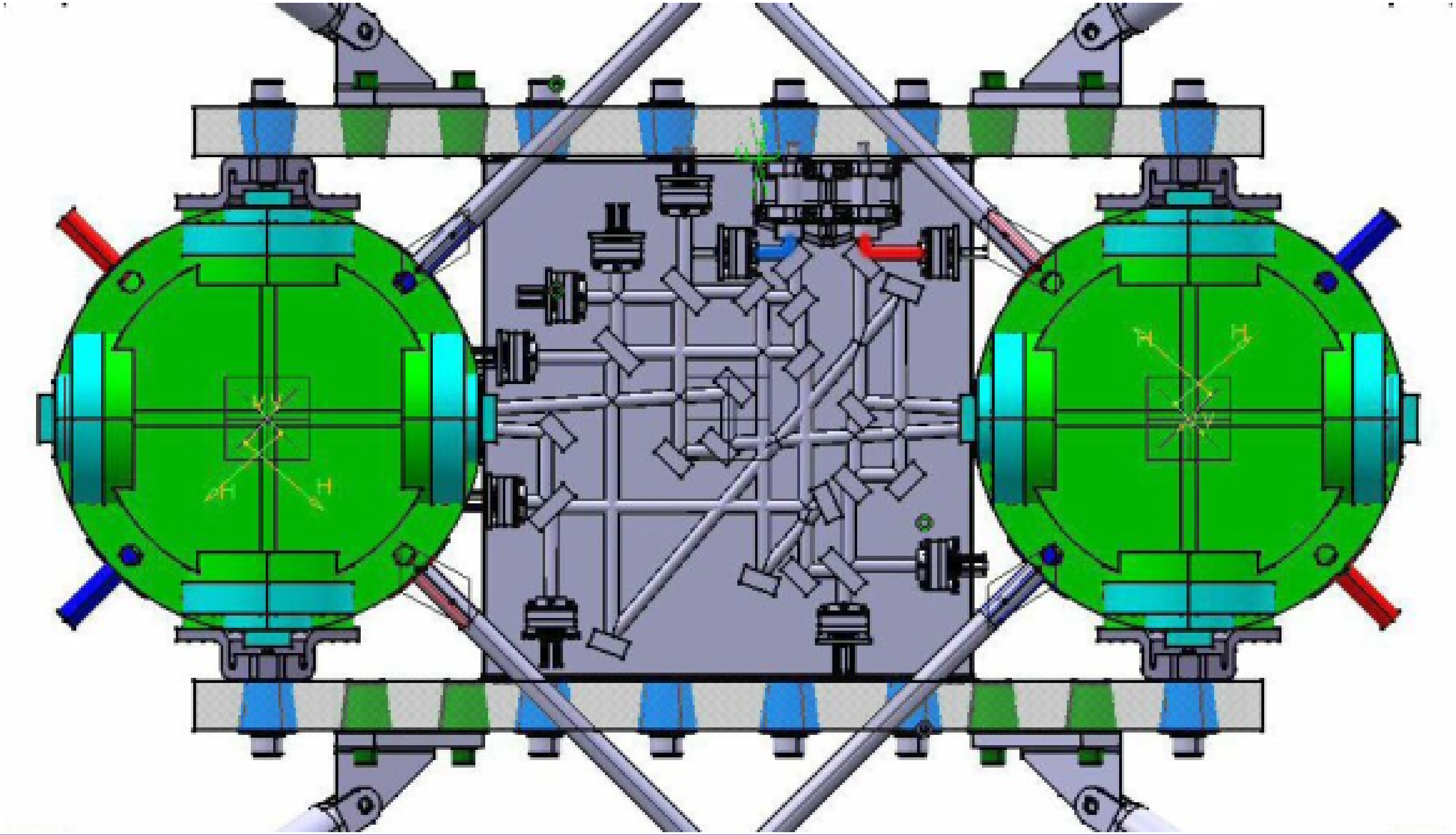
Optical Bench optical paths phase reference



Optical Bench optical paths
Unequal path length ifo



Optical Bench optical paths
Laser monitoring detectors



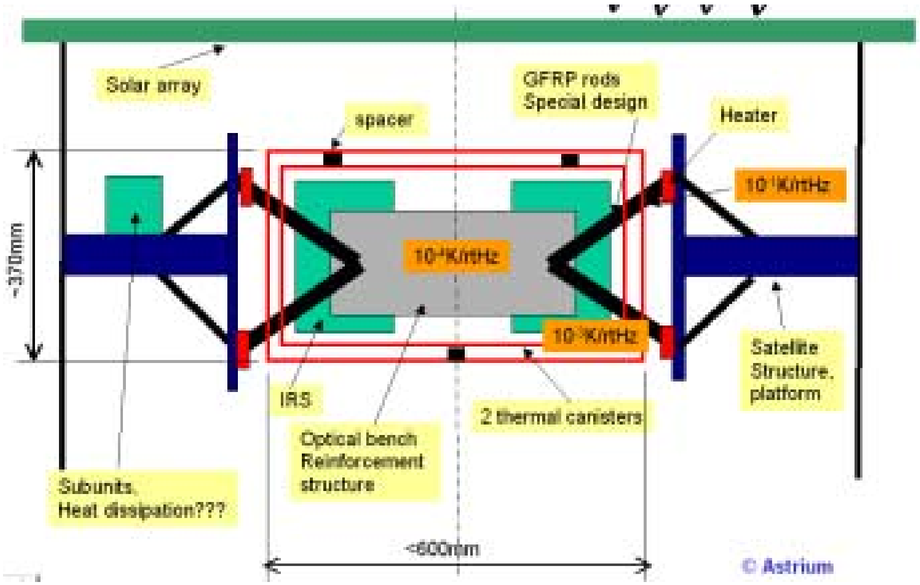
Current status optical bench

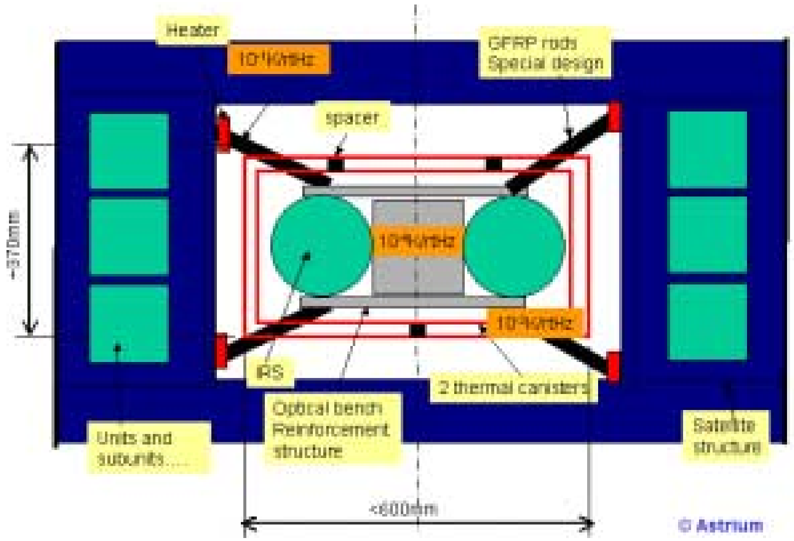
- Interface OB-IRS consolidated
- Solid opto-mechanical design LTP
  (stiff H-type OB, Min Eigen freq. > 120 Hz)
- Pre-investigations phase completed successfully December 2003
- AIVT plan optical bench consolidated and documented in
  "OB EM assembly integration and testplan" TN-AIT-26-12-2002
- Upcoming EM Detailed Design review (milestone)
  EM DDR on February 25th 2003
- When OK → Manufacturing release

Future outlook

- Assembly, Integration and Testing of the EM optical bench system
- Performance verification EM OB
- Environmental testing EM OB (all to be completed before end September 2003)
- Adding the Inertial sensor system to the EM OB (4rd quarter 2003) and perform additional tests
- Upcoming activity “Ground testing of LTP”: Environmental and functional testing of completely integrated EM LTP

Thermal concept





Lisa Technology Package

Project schedule